The Angle Orthodontist

January • 1958

Published Quarterly by
The Edward H. Angle Society of Orthodontia

Published Quarterly by the
EDWARD H. ANGLE SOCIETY OF ORTHODONTIA
Zuelke Building, Appleton, Wisconsin
Subscription Rates: $6.00 per year, Canada $6.25,
other foreign countries $6.50.

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Volume 28, Number 1

Contents

1 • SOME ASPECTS OF FACIAL DEPTH IN CLASS II, DIVISION 1 MALOCCLUSION
Martin R. Kean, M.D.S.

12 • A RADIOGRAPHIC CEPHALOMETRIC STUDY OF THE CENTRAL AUSTRALIAN ABORIGINAL
A. H. Craven, D.D.S., M.S.

36 • THE CONGENITALLY ABSENT PREMOLAR PROBLEM
Joseph R. Valinoti, Jr., D.D.S.

47 • ASPECTS OF GROWTH IN THE CRANIUM, MANDIBLE, AND TEETH OF THE RABBIT AS REVEALED THROUGH THE USE OF ALIZARIN AND METALLIC IMPLANTS
Leslie C. Erickson, D.D.S.
Alfred L. Ogilvie, D.D.S., M.S.

57 • ANNA HOPKINS ANGLE

ANNA HOPKINS ANGLE

1872-1957

Some Aspects of Facial Depth in Class II, Division 1 Malocclusion*

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Angle[1] was of the opinion that "the facial deformity produced by malocclusion in each Class is so distinctive and constant that after some practice the orthodontist may even classify with considerable accuracy the malocclusion of the people he meets without an actual examination of their teeth." He maintained that the facial form associated with Class II, division 1 malocclusion was influenced primarily by the size and position of the mandible. Despite valid criticism by Case[7] and Simon[21] this hypothesis was accepted almost universally, and it was restated by Brodie[5] just before the introduction of cephalometric radiography.

Fisk et al.[14] summarized the conclusions of recent studies dealing with Class II, division 1 malocclusion. Unfortunately, lack of critical analysis of the original findings of these studies detracted from the potential value of their summary.

Preference has been given to the measurement of angular relationships in cephalometric radiography. Linear determinations permit further appraisal of an area or part in terms of its influence on the configuration of the whole face. An advantageous combination of angular and linear measurements is exemplified by the study of Björk.[4]

Elsasser and Wylie[13] and Wylie[25] determined the "effective" contribution of various facial dimensions to the form of the bony profile by measuring projected, instead of actual, distances between two landmarks. In the latter study, for instance, the effective length of the mandible was obtained by measuring the distance between the head of the condyle and gnathion as a projection on the Frankfort horizontal. Wylie[25] and Wylie and Johnson[36] made separate analyses of facial height and depth. However, these variables may be studied together when two coordinates perpendicular to each other are used, one related to a suitable line of reference such as sella-nasion (Williams[23]) or the Frankfort horizontal (Coben[8] and Craig[9]).

In the present study the method of projecting distances between different landmarks on two coordinates was used in the analysis of the cephalometric radiographs of two groups of children, one with "normal" occlusion and the other with Class II, division 1 malocclusion. The purpose of this study was to compare the faces of these children, emphasizing particularly variations in facial depth in relation to the type of occlusion.

MATERIAL AND METHOD

Two groups each of thirty-six white children, 8 to 10 years of age, with non-mutilated dentitions, were selected from primary schools in Dunedin, New Zealand. The children with Class II, division 1 malocclusion were included in the Class II group: the others, having "normal" occlusion, formed the control group.

The lateral head radiographs of all seventy-two children were taken with a Margolis cephalostat with the teeth in

*Based on thesis submitted in partial fulfillment for the degree of M.D.S. (N.Z.). University of Otago Dental School.

occlusion. The necessary radiographic outlines were traced in the usual manner. For the location of different landmarks, the definitions given by Brodie[6], Downs[10], and Björk[4] were used. A specially constructed glass scale made it possible to read linear measurements from each tracing directly in true millimeters (Fig. 1).

In order to construct this scale, millimeter graph paper with accentuated centimeter lines was drymounted on a piece of thick cardboard which in turn was firmly attached to a bench. Fine stainless steel wires were stretched along the horizontal and vertical centimeter lines and kept in place with scotch tape. The resulting stainless steel wire mesh was placed in the midline of the Margolis cephalostat, corresponding to the position of the midsagittal plane of the head, and radiographed.

Transferral of the undistorted but slightly enlarged centimeter squares from the radiograph onto the glass plate was complicated by the need to obtain millimeter divisions within the centimeter squares.

On the radiograph of enlarged centimeter squares, a standard series of squares having 10 divisions per side was "fitted" by image projection. By removing the radiograph and in its place exposing a photographic glass plate to the fitted image, a permanent scale duplicating the enlarged millimeter squares was obtained. Thus, a millimeter on the scale was enlarged to the same extent as a given distance in the midsagittal plane is enlarged on a radiographic film since the midsagittal plane-film distance is constant in the Margolis cephalostat.

Any distance between two landmarks in the midsagittal plane of the subjects studied could now be read directly from a tracing placed on the glass scale. All readings were in actual millimeters and the error incurred was less than one per cent.

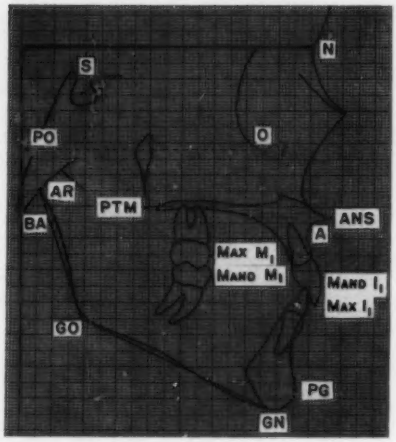

Fig. 1 Orientation of a tracing on the specially constructed millimeter scale for the coordinate method of cephalometric analysis used in this study. One millimeter on this scale is enlarged to the same extent as a given distance in the midsagittal plane of the head is enlarged on the radiographic film. The locations of the various cephalometric points are also shown.

This technique also permitted the measurement of the distance between two given points, one of which was outside the midsagittal plane. Measurement of the length of the mandible between articulare and pogonion may serve to illustrate this point. The shadows of the left and right sides of the mandible are never actually superimposed on cephalometric radiographs. If mandibular length is measured separately on right and left sides, the distance between articulare and pogonion will be less on the side closer to the film (left) and greater on the opposite side because the millimeter scale compensates for radiographic enlargement only at a specific object-film distance, the object in this case being the midsagittal plane. However, when the midpoint between the two

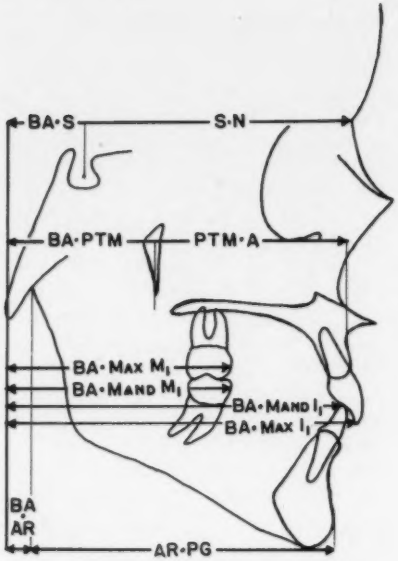

Fig. 2 Analysis of craniofacial depth.

registrations of articulare is taken, the average distance between pogonion and the left and right articulate points is obtained.

Tracings of the cephalometric radiographs were orientated on the glass scale in such a manner that one horizontal line passed through nasion, parallel to the Frankfort horizontal line (the nasion-parallel plane of Krogman[16]), and one vertical line passed through basion. These lines are abscissa and ordinate of the coordinate system (Fig. 1).

Cranial and facial depths were measured as *projections* on nasion-parallel, as follows (Fig. 2):

1. Cranial Base
   - Ba - N: total length of cranial base
   - S - N: anterior component of cranial base
   - Ba - S: posterior component of cranial base
2. Upper Face
   - Ba - A: total upper facial depth
   - Ba - Ptm: distance between maxilla and posterior limit of cranial base
   - Ptm - A: maxillary length
3. Lower Face
   - Ba - Pg: total lower facial depth
   - Ba - Ar: distance between mandible and posterior limit of cranial base
   - Ar - Pg: mandibular length

Anterior and posterior facial heights were measured as projections on the ordinate perpendicular to nasion-parallel as follows (Fig. 3):

1. Anterior Facial Height
   - N - Gn: total anterior facial height
   - N - ANS: upper anterior facial height
   - ANS - Gn: lower anterior facial height
2. N - Go: total posterior facial height
   - N - Ar: upper posterior facial height
   - Ar - Go: lower posterior facial height

In order to determine the horizontal relationships of the dental arches to the posterior limit of the cranial base, the projected distances from basion to the mesial surfaces of the permanent maxillary and mandibular first molars on nasion-parallel (N//) were measured (Ba-M$_1$max., and Ba-M$_1$mand.) (Fig. 2). The distance between the incisal margins of the maxillary and mandibular central incisors in the sagittal plane (overjet) and in the vertical plane (overbite) were obtained indirectly as follows (Fig. 3):

1. Overjet
   Ba-I$_1$max. minus Ba-I$_1$mand., as projected on the abscissa
2. Overbite
   N// - I$_1$max. minus N// - I$_1$ mand., as projected on the ordinate

The facial angle (N-Pg-N//) and the

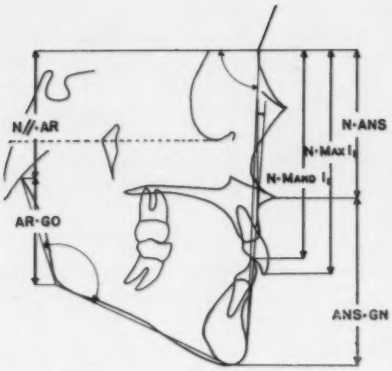

Fig. 3 Analysis of craniofacial height and the angles measured.

angle of convexity (N-A-Pg), both descriptive of the bony profile according to Downs[10], were obtained in each instance (Fig. 3). The gonial angle (Ar-Go-Gn) and the Frankfort mandibular plane angle (FH-Go-Gn) were the only other angular measurements made.

The data for each sample were analyzed statistically. The mean, standard deviation, and range of each measurement were determined. The difference between the means for the groups was statistically significant when the Critical Ratio was equal to or greater than 2.5 (C.R. = >2.5), and the probability equal to or less than 0.05 ($p = <0.05$).

The sex ratios for the two samples of children were not identical. Since statistically significant differences between a few mean values of males and females were observed within the Class II and control groups, it was necessary to compute weighted means and standard errors of the means in order to draw valid conclusions from the findings when comparing children having normal occlusion and Class II, division 1 malocclusion.

Findings

The means, standard deviations, and levels of statistical significance between means are presented in Table I. Unless stated otherwise, all differences mentioned in the following report of the findings are statistically significant.

Facial depth (Table I and Figure 4)

Cranial Base. Compared to the control group, the Class II group has a greater mean total cranial base length (C.R. 3.5) as well as a longer posterior component (C.R. 2.8).

Upper Face. The mean total facial depth (Ba-A) is greater in the Class II group than in the control group, but this difference is not statistically significant. The difference between the groups for the horizontal distance from maxilla to basion (Ba-Ptm) approaches statistical significance (C.R. 2.4).

Lower Face. Average mandibular length (Ar-Pg) is short in the Class II group (C.R. 2.9). Although the distance Ba-Ar is small, it is significantly

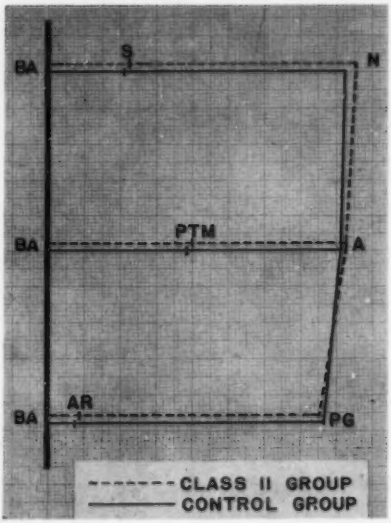

Fig. 4 Mean projected craniofacial depths of 36 children with normal occlusion (control group) and 36 children with Class II, division 1 malocclusion (Class II group). Age range 8-10 years.

TABLE I

Craniofacial dimensions measured as projections on a coordinate system, and angular measurements of 36 children with normal occlusion (Control group) and 36 children with Class II, division 1 malocclusion (Class II group), aged 8-10 years.

		Control Group		*Class II Group*			
Variate		*Mean*	*S.D.*	*Mean*	*S.D.*	*C.R.*	*p*
Cranial Base Length	Ba-S	21.0 mm	2.59	22.5 mm	1.97	2.8	.001<p<.01
	S-N	61.0	3.55	62.8	2.90	2.4	.01 <p<.02
	Ba-N	82.2	4.03	85.1	3.08	3.5	p<.001
Upper Facial Depth	Ba-Ptm	38.5	2.66	39.8	2.20	2.4	.01 <p<.02
	Ptm-A	42.5	1.75	43.2	2.10	1.5	.14 <p<.15
	Ba-A	81.0	3.44	82.8	3.68	2.2	.03 <p<.04
Lower Facial Depth	Ba-Ar	7.7	1.49	8.7	1.48	3.0	.001<p<.01
	Ar-Pg	68.8	3.87	65.7	5.22	2.9	.001<p<.01
	Ba-Pg	76.8	4.20	74.5	5.16	2.1	.03 <p<.04
Anterior Facial Height	N//-ANS	44.5	2.33	45.2	2.21	1.3	.19 <p<.20
	ANS-Gn	55.4	3.12	54.7	3.95	0.8	.40 <p<.41
	N//-Gn	99.3	6.73	99.9	4.70	0.4	.65 <p<.66
Posterior Facial Height	N//-Ar	35.4	3.58	37.2	4.21	2.0	.04 <p<.05
	Ar-Go	37.1	2.54	36.9	2.89	0.4	.68 <p<.69
	N//-Go	72.5	3.27	74.2	4.74	1.7	.08 <p<.09
Relation of Dentition to Cranial Base	Ba-Max.M1	55.5	3.74	56.8	3.21	1.5	.12 <p<.13
	Ba-Max.I1	82.6	3.84	85.0	4.91	2.3	.01 <p<.02
	Ba-Mand.M1	55.5	4.13	53.8	3.66	1.9	.06 <p<.07
	Ba-Mand.I1	80.3	3.77	78.5	4.33	1.8	.07 <p<.08
Overbite	N//-Max.I1 ..... minus N//-Man.I1	3.4	2.02	5.9	2.01	5.4	p<.001
Overjet	Ba-Max.I1 ..... minus Ba-Mand.I1	2.4 mm	0.63	6.5 mm	3.56	6.9	p<.001
Facial Convexity	N-Pg-N//	86.5°	2.63°	83.7°	3.55°	3.9	p<.001
	N-A-Pg	+4.5°	3.77°	+9.8°	4.22°	5.6	p<.001
Gonial Mand. Plane	Ar-Go-Gn	126.6°	5.76°	124.4°	5.23°	1.7	.08 <p<.09
	Go-Gn-N//	25.7°	3.81°	24.7°	5.60°	0.8	.40 <p<.41

larger in the Class II group than in the control group (C.R. 3.0). In view of the similarity in the values for the gonial and mandibular plane angles, it seems that the mandible is in an anterior position in relation to the posterior limit of the cranial base in Class II, division 1 malocclusion. An analysis by the author of data on two patients reported by Coben[8] gave a similar finding. The difference between the average total lower facial depths (Ba-Pg) in the two groups of children is not statistically significant (C.R. 2.1).

Facial height (Table I)

Anterior Facial Height. Mean values for upper, lower, and total anterior facial heights are similar in the two groups. This is borne out by the close approximation of the percentage ratios of upper to lower anterior facial heights in the control 44.6 : 55.4 and Class II groups (45.3 : 54.7). The latter finding conforms closely to that given by Wylie[23] for individuals with malocclusion of all types (45.8 : 54.2).

Posterior Facial Height. There are no statistically significant differences between the mean values pertaining to this dimension.

Relationship of dentition to cranial base (Table I)

The average distances from basion to the permanent maxillary and mandibular first molars are similar in the two groups. The difference between the average distances from basion to the mandibular central incisor (Ba-Mand. I.) is not statistically significant (C.R. 1.8). However, in the average child with Class II, division 1 malocclusion the maxillary central incisor is in a more forward position as measured from basion (Ba-max.I_1) than in an average child with normal occlusion. This is the only difference between measurements relating the dentition to the cranial base that approaches statistical significance (C.R. 2.3).

As expected, overbite and overjet are considerably larger in children with Class II, division 1 malocclusion than in those with normal occlusion (C.R. 5.4 and 6.9, respectively).

Angles (Table I and Figure 4)

The facial angle was significantly small (C.R. 3.9) in the Class II group. The mean value for the angle of convexity in the Class II group was twice that of the control group (C.R. 5.6). The gonial and mandibular plane angles showed no statistically significant differences between the two groups of children.

The above conclusions derived from group statistics show their limitations when applied to individuals. This was evident when three children of the Class II group (Table III), with the greatest depth of the cranial base and

TABLE II

Data for a child of the control group (R12) whose craniofacial dimensions correspond closest to the mean data for that group, according to the method of analysis used in this study. (This child's tracing was chosen to represent the "average" face of the control group).

Variate		*R12*	*Mean, Control Group*
Cranial Base Length	Ba-S	18.0 mm	21.0 mm
	S-N	63.0	61.0
	Ba-N	81.0	82.2
Upper Facial Depth	Ba-Ptm	35.5	38.5
	Ptm-A	44.0	42.5
	Ba-A	79.5	81.0
Lower Facial Depth	Ba-Ar	6.0	7.7
	Ar-Pg	69.0	68.8
	Ba-Pg	75.0	76.8
Anterior Facial Height	N-Gn	102.0	99.3
Posterior Facial Height	N//-Go	76.5	72.5
Overbite		4.5	3.4
Overjet		1.5 mm	2.4 mm
Facial Angle		86.5°	86.5°
Angle Convexity		+5.5°	+4.5°
Gonial Angle		131.5°	126.6°
Mand. Plane Angle		26.0°	25.7°

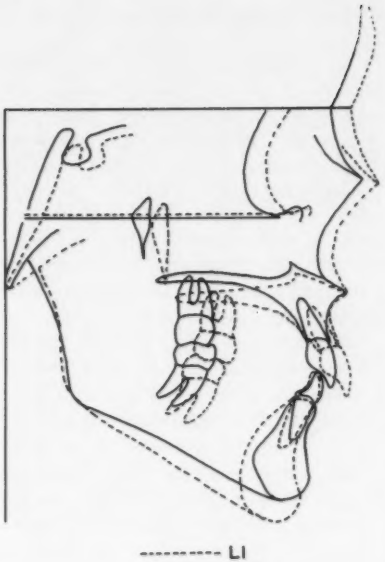

Fig. 5 Tracing of a child with Class II, division 1 malocclusion (L1) having the greatest depth of the cranial base within the Class II group, superimposed on a tracing (R12) representing the average face of the control group.

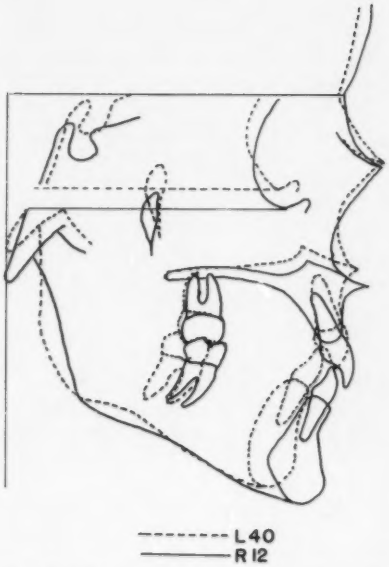

Fig. 7 Tracing of a child with Class II, division 1 malocclusion (L40) having the smallest depth of the lower face within the Class II group, superimposed on a tracing (R12) representing the average face of the control group.

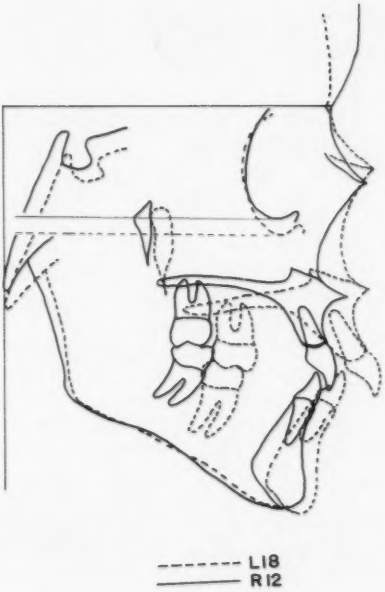

Fig. 6 Tracing of a child with Class II, division 1 malocclusion (L18) having the greatest depth of the upper face within the Class II group, superimposed on a tracing (R12) representing the average face of the control group.

upper face (L1 and L18, respectively) and with least depth of the lower face (L40), were compared with the "average" face of the control group. One child with normal occlusion (R12, Table II) was chosen to represent this "average" face since his facial dimensions corresponded closest to the mean values for the control group.

Tracings of the lateral head radiographs of L1, L18, and L40 are superimposed upon a tracing of R12 in Figs. 5, 6, and 7 respectively. The coordinate system used in this study served as the method of superimposition. Each of the three tracings was superimposed upon that of R12 along nasion-parallel and its perpendicular through basion. The intersection of the two coordinates became the point of registration. Although deviations in depth constitute the major point of interest in this discussion, overall variations in facial configuration, at least from the lateral aspect, are illustrated.

L1 typifies the facial form associated with Class II, division 1 malocclusion according to the statistical findings of the present study (Fig. 5); L18 has a marked maxillary protrusion (Fig. 6); L40 exemplifies the facial form traditionally associated with Class II, division 1 malocclusion (Fig. 7). These comparisons illustrate the wide range of facial configurations which occur among individuals with this type of malocclusion. The variability at the three planes of facial depth, namely at the level of the cranial base, upper and lower face, is particularly striking.

Discussion

Generally speaking the mandible is shorter than average in Class II, division 1 malocclusion (Craig[9], Drelich[11], Gilmore[15], Nelson and Higley[19], and Reidel[20]), and this is confirmed by

TABLE III

Craniofacial dimensions of children with Class II, division 1 malocclusions and the mean data for the control group. "L18" having the greatest depth of upper face, "L1" having the greatest length of the cranial base and "L40" having the least depth of the lower face.

Variate		*L18*	*L1*	*L40*	*Mean, Control Group*
Cranial Base Length	Ba-S	21.0 mm	21.0 mm	20.0 mm	21.0 mm
	S-N	60.0	66.0	60.5	61.0
	Ba-N	81.0	87.0	80.5	82.2
Upper Facial Depth	Ba-Ptm	41.5	41.0	37.0	38.5
	Ptm-A	46.5	42.0	43.0	42.5
	Ba-A	88.0	83.0	80.0	81.0
Lower Facial Depth	Ba-Ar	11.0	9.0	7.5	7.7
	Ar-Pg	68.5	66.0	62.3	68.8
	Ba-Pg	79.5	75.0	70.0	76.8
Anterior Facial Height	N-Gn	103.0	107.0	97.5	99.3
Posterior Facial Height	N//-Go	74.5	78.0	71.0	72.5
Overbite		6.0	5.0	7.0	3.4
Overjet		7.5	7.5	3.0	2.4
Facial Angle		89.0°	83.5°	83.5°	86.5°
Angle Convexity		+17.5	+7.0	+13.0	+4.5
Gonial Angle		127.5	130.0	117.5	126.6
Mand. Plane Angle		21.5	28.5	25.0	25.7

the findings of the present study.

Gilmore[15] found that the posterior border of the mandibular ramus bears a similar relationship to the cranial base in excellent occlusion and Class II, division 1 malocclusion. According to the present study, however, the mandible is situated in a more anterior position in the latter relative to the posterior limit of the cranial base. The integration of these two components of lower facial depth, namely the shorter length of the mandible and its forward position, has a "cancelling out" effect in Class II, division 1 malocclusion leaving the chinpoint at virtually the same horizontal distance from basion as in normal occlusion.

The existence of a constant proportional relationship between the permanent mandibular first molars and the mandible in Class I and Class II malocclusions was proposed by Elman[12]. Using more refined statistics in a similar study Gilmore[15] showed conclusively that this relationship was not constant. The results of the present study do not support Elman's contentions, nor are they offered as positive confirmation of Gilmore's findings. Yet it must be admitted that the similarity in Ba-M_1 mand. measurements, the anterior position of the mandible, and its smaller length in the Class II group are indicative of some differences in the anteroposterior relationship of the permanent mandibular first molar to the mandible in normal occlusion and Class II, division 1 malocclusion.

Baldridge[2,3] stated that the permanent maxillary first molar maintains the same relationship to the face and cranium in Class I and Class II malocclusions. At first glance the results of the present study substantiate this claim since the permanent maxillary first molars are located at similar distances from basion in both the control and Class II groups. However, when the longer cranial base and the anterior position of the maxilla are taken into consideration, it is evident that the relationship of these teeth to the face and cranium may vary according to the type of occlusion.

Although overjet and overbite received relatively little attention in the present study, two aspects of the findings are worthy of comment. First, there is some indication that the large overjet in Class II, division 1 malocclusion is determined by the position of the upper central incisor (C.R. 2.3) rather than by the lower one (C.R. 1.8). Secondly, the association between larger overbite and unchanged anterior facial height in the Class II group does not differ significantly from zero ($r = -0.158$). This finding is at variance with Wylie's[24] observation that individuals with severe overbite have a shorter lower anterior facial height than those with slight overbite.

The overall depth of the upper face was similar for children with normal occlusion and those with Class II, division 1 malocclusion. Ptm-A, one of the two variables constituting the horizontal distance from point A to the posterior limit of the cranial base, did not differ in the two groups. The other variable, Ba-Ptm, was larger in the Class II group, the difference almost reaching statistical significance (C.R. 2.4). These findings suggest that, when Class II, division 1 malocclusion prevails, the depth of the upper face might be influenced more by a change in the horizontal relationship of the maxilla to the posterior limit of the cranial base, than by an increase in maxillary length.

The greater depth of the cranial base in the Class II group is attributed to an increase in its effective length. There are three possible explanations for this change. First, there could be an increase in the actual lengths of the anterior or posterior components of the cranial base as suggested by Björk[4]

but not verified by Craig[9] or Gilmore[15]. Secondly, an increase in the effective length of the cranial base could be related to changes in its flexure (Björk[4], Lindegärd[17]). Thirdly, there is the possibility of a change in the spatial relationship of the cranial base to the Frankfort horizontal plane, due to positional variations either in this plane or in the cranial base. According to Craig[9], however, the anterior and posterior cranial bases lie at practically the same angle to the Frankfort horizontal plane in Class II, division 1 malocclusion and excellent occlusion.

The use of the facial angle to describe variations in the depth of the lower face presupposes the relative stability of nasion and, therefore, similarity of the effective lengths of the cranial base in normal occlusion and Class II, division 1 malocclusion. In terms of the findings of the present study it is conceivable that the facial angle is smaller in the Class II group because nasion is situated anteriorly (C.R. 3.5) while the position of pogonion is less affected (C.R. 2.1).

In the present study only one (nasion) of the three profile points (nasion, point A, and pogonion) differed to a statistically significant degree in its horizontal relationship to the posterior limit of the cranial base. However, among individuals, variations at all three levels of craniofacial depth were responsible for the greater convexity of the profile in children with Class II, division 1 malocclusion.

The mean findings suggest that the typical face of children with Class II, division 1 malocclusion differs from previous concepts, including that of Angle. Average findings or a generalized concept of type *cannot* be applied to the individual inasmuch as each child is typical for himself. This fact is of great importance in orthodontic diagnosis and treatment planning.

Summary

A cephalometric radiographic appraisal was made of thirty-six children with Class II, division 1 malocclusion and a similar number having normal occlusion. All children were between eight and ten years of age.

To facilitate the coordinate method of analysis utilized in this study, a glass scale was used to measure tracings from lateral head radiographs.

The facial form of children with Class II, division 1 malocclusion was resolved at three levels of craniofacial depth. In terms of the mean findings, the typical facial configuration of these children was expressed as an increase in the effective length of the cranial base, concomitant with similar depths of the upper and lower face.

As an important aspect of this study, namely that of individual variation, three children with Class II, division 1 malocclusion illustrated: (1) the individuality in facial configuration of children grouped according to class of malocclusion, (2) three typical, but different variants of the facial form associated with this malocclusion, (3) the limitations of applying group data to individuals particularly for the purpose of clinical evaluation.

P. O. Box 647

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A Radiographic Cephalometric Study of the Central Australian Aboriginal*

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Introduction

The Australian aboriginal holds a unique position in anthropology, showing the characteristics of at least two of the three main races of man. Indeed, Sir Arthur Keith has said, "of all the races of mankind now alive, the aboriginal race of Australia is the only one which in my opinion, could serve as a common ancestor for all modern races."[25] Thus, it was of interest to compare cephalometric measurements of a living tribe of Central Australian aboriginals with those of other living races.

The racial origin and purity of the Australian aboriginal have been the subject of much discussion. In 1887, Turner[36] believed the Australian aboriginals to be a pure race, but admitted wide variations. Later, Klaatsch[26] believed there was one race, but that local differences were specializations due to the environmental conditions. As we shall see, Morant[30] subscribed to the idea of two racial groups.

Due to the paucity of skeletal material and the absence of stone implements, the majority of investigators believe that man did not evolve on the continent of Australia. The closely allied Dravidian race of S. E. Asia seemed to suggest that racial migration took place. Indeed, evidence was offered by the presence of another placental, the wild dog (canis dingo), similar to that of S.E. Asia.

On the basis of racial investigations in Australia, Birdsell[2] suggested three major migrations from the mainland of Asia, via the Sahul shelf. The Oceanic Negrito arrived during the early part of the Fourth Glacial period and, according to Birdsell, were characterized by "moderate round headedness, low nasal relief and a very short and narrow face." The arrival of the second major migration, during the mid-portion of the Fourth Glacial period, displaced the first wave southward. These later arrivals, the Murrayian group, were described by Birdsell as having a long, low, and narrow cranial vault. The general facial impression, he added, was "that of a coarse and rough hewn caucasoid type". The third racial group to enter the Autralian continent from the north, the Carpentarian element, arrived late in the Fourth Glacial period or Early Recent period. The cranium was of moderate length and height combined with extreme narrowness. With regard to the face, Birdsell stated. "The teeth are large, prognathism is marked, and the chin of the mandible ill-developed."

All these racial elements are blended in varying degrees, in different regions, to form the present day Australian aboriginal. Birdsell believed the aboriginals from the Central Desert area, the region of this study, to be a mixture of two racial elements, the Murrayian and Carpentarian.

*Based on a thesis submitted as partial fulfillment of the requirements for the degree of Master of Science in Orthodontia in the Graduate College at the Chicago Professional College of the University of Illinois, 1952.

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Although many craniometric investigations have been undertaken in collections of adult skulls to determine inter-racial differences, the scarcity of infant and adolescent crania has prevented the comparison of growth patterns in different races. In the latter respect, the techniques of radiographic cephalometry offer distinct advantages in being applicable to large numbers of healthy infants and adolescents.

As early as 1863, T. H. Huxley[24] pointed out the dolicocephalic cranial form of the Australian aboriginal skull and commented on the degree of prognathism of the maxilla. Huxley, one of the earliest interested in craniometry, superimposed tracings of the sagittal sections of the crania of several races on the "basi-cranial axis", a line joining basion and the spheno-ethmoidal junction. Although his choice of a reference line was excellent, the use of a single specimen for the comparison of racial groups did not allow for intra-racial variation.

Somewhat later, Turner[37] directed attention to the relationship of the cranium to the dental arches in the Australian aboriginal. He reported on the large size of the teeth and the dimensions of the palate and observed the protrusion of the upper incisor teeth with a high frequency of edge-to-edge occlusion of the incisor teeth. Turner speculated that this occlusion might have been produced in two possible ways, either compensation by modification of the form and size of the lower jaw, or a change in the construction of the skull itself. By comparing aboriginal and European mandibles, he eliminated the former possibility and assumed that changes in the skull influenced the relationships of the face.

Following a complete analysis of the cranium and face in the Roth Collection of aboriginal skulls in Australia, Klaatsch[26] drew attention to the curvature of the cranium in norma lateralis. He analysed this and stated, "the variations of the frontal, parietal and occipital as components of the sagittal curve of the cranium, may become interesting in further examinations of the racial specialization of mankind from an ancestral stage." He pointed out the reduced size of the anterior nasal spine, the degree of alveolar prognathism, the large teeth and the extremely large dental arches which allowed space for the eruption of a fourth molar. After comparing the Australian aboriginal cranium with the Neanderthal skull and Pithecanthropus erectus, Klaatsch concluded . . . . . "the positive anatomical facts are overwhelming in emphasis of the fact that the Australian Aboriginals are a relic of the oldest type of mankind."

Since the profile had always been of interest in the determination of racial differences, Luthy[29] employed an angular analysis of points on the profile to the Frankfort Horizontal. Of all the races compared, the Australian aboriginal was found to be most prognathic both in total face and middle face prognathism. He mentioned that alveolar prognathism was usually the same for both jaws. However, his conclusions on the Australian aboriginals were based on thirteen skulls from collections in Europe. Perhaps, a criticism may be leveled at the use of skull collections on two points; first, the sex of the skull was often unknown and, secondly, skulls sent to the collections most frequently possessed unusual features.

In a thorough investigation of the dentition and palate of the Australian aboriginal Campbell[15] concluded that the teeth and palate were "probably larger than any other living race." It is interesting to note that of the six hundred and thirty skulls examined by Campbell only fifty nine were infants and adolescents.

In 1927, Hellman[21] examined the face and occlusion of the Australian aboriginal skull and compared the findings with Hindu and American White skulls. Linear and angular measurements were taken from the nasion-porion plane, registered at porion. Hellman showed the Australian aboriginal face to be further forward than the other two races, a finding similar to that of Luthy in 1912.

Stressing the need for statistical investigations of different races, Morant[30] pooled the data from previous craniometric studies on the Australian aboriginal. Analysis of this aggregate data led Morant to conclude that the Australian aboriginal was composed of two slightly different racial types; but, on the facial measurements recorded, there was no difference between the faces of the two types. Morant also computed the degree of variability of the Australian aboriginals, finding them less variable than a modern white race of the 17th century from a local area, but more variable than Egyptian skulls from the 26-30th dynasty.

The Australian aboriginal skull possesses characteristic non-metrical features. Burkitt and Hunter[11] mentioned the development of the supraorbital ridge, the unusual formation of the nasal bones, and the rounded orbital margin which they believed due to excessive masticatory function from the coarse diet. They also observed the curved inferior border of the mandible with the convexity downward and the ascending ramus almost at right angles to the body. In a later study, Burkitt and Lightoller[12] examined the inferior border of the nasal aperture and noted the frequency of a small nasal spine in the Australian aboriginal. The degree of alveolar prognathism, the axial inclination of the teeth, the size of the teeth and proximity of the apices to the inferior nasal border, and the mode of occlusion, were suggested as influences on the form of the anterior nasal spine.

The application of a radiographic technique to craniometry was advanced by Pacini[31]. He showed the accuracy of the method to be within the limits of error allowed in the 1906 Monaco Agreement of Anthropologists. Only radiographs in norma lateralis were discussed, and readily discernible midline structures formed the basis for a method of analysis.

With the subsequent development of a cephalometer by Broadbent,[6] a new tool was added to the armamentarium of the physical anthropologist. The cephalometer obtained radiographs of living individuals in both norma lateralis and norma frontalis. This technique allowed the comparison of skeletal material with the living head and permitted the selection of previously inaccessible facial and cranial landmarks. But, for the anthropologist, the disadvantage of the Broadbent--Bolton cephalometer was the size of the equipment which did not allow for field work in racial investigations. Even so, Broadbent[7] and Brodie[9] have studied the growth of the head in the young American white male.

Recently, Bjork[3] used the principles outlined by Broadbent and designed a portable cephalometer. The distance from the median plane of the head to the film was fixed, and the x-ray tube, also at a fixed distance, was aligned perpendicular to the film surface by an optical system.

With this cephalometer Bjork first examined a large number of Swedish boys and conscripts for variation in form of the cranial base and face. The difference in age between the two groups permitted appraisal of the changes which occurred with growth. Then, in 1948, Bjork[4,5] extended his investigations of racial prognathism to the Bantu, a primitive tribe of mixed origin in South Africa. Adult males

and boys were examined, using the same method as that applied to the Swedes. Again, variation and growth were studied. Comparison with the Swedish material led to the conclusion that racial variation was not in the degree of prognathism, but rather in the nature of the prognathism. Little was said of the growth changes in the Bantu.

The present investigation was undertaken to compare the Central Australian, an archaic caucasoid, with these other living races.

Material

Mr. John Heath obtained lateral head radiographs of fifty-six Central Australian aboriginals and stated,[20] "the radiographs are of certified pure blood aboriginal children and young adults." The aboriginals investigated lived in the Hermannsburg Mission and Haast Bluff reserve area, about 200 miles N.W. of Alice Springs. Alice Springs is in the lower central part of Northern Territory, about 160 miles north of the border of South Australia. The tribes most likely represented in this investigation are the Pintubi and Pitjandjara. Mr. Heath's material is the subject of the present investigation.

Analysis of the material showed the age range and sex distribution in the following groups.

Age	*No. Males*	*No. Females*	*Total No.*
4 - 11 years	12	15	27
12 - Young Adults. (about 20 yrs.)	9	20	29
	—	—	—
	21	35	56

This division gives two age groups, a young group with a mean age of 7.5 years and an adolescent group with a mean age about 15 years.

Method

Mr. Heath obtained lateral head radiographs by the use of a head holding device and a portable x-ray machine supplied by a gasoline driven generator. The distance of the tube to film surface was thirty-six inches. For the present investigation the radiographs were accurately reproduced on five inch by seven inch negatives in the Illustration Department, University of Illinois, and then the negatives were traced.

The whole group was examined and then subdivided into sex and age groups to determine any significant differences. Throughout the investigation angular readings and proportional measurements were used. This allowed the comparison of form irrespective of size and permitted comparison of the racial groups.

Since the cranial outline of the Australian aboriginal had been well investigated, it was decided to examine both calvarium and face from the point of view of mean values, variation within the group and such growth changes as would be indicated in such a small sample. Thus, the investigation was divided into three parts, namely, analysis of the cranial outline, analysis of the facial structures and profile, and comparison of the findings in the Australian aboriginal with those of other races.

Analysis of the cranial outline

In addition to the overall height and length of the cranium, expressed as an index, the cranial outline was reduced to a simply constructed geometric form. In this construction, it was decided to follow the suggestion of Wilder[39] that the joining of the points nasion, bregma, lambda and basion would result in a quadrangle which represented the cranial outline. Since basion was obscured by the radiographic technique, Bolton point was used as the posterior end of the cranial base. At the site of greatest convexity of the cranial outline opposite each

face of the quadrangle, a secondary point was located (see glossary of terms). By including the cranial base angle, NSBo, and joining the constructed points to the quadrangle points, a polygon was constructed which fully expressed the cranial outline, figure 1. The degree of curvature of the frontal, parietal and occipital bones was read from the inside angles of the polygon while the inclination of the frontal and occipital bones was read from the inner angles of the quadrilateral.

Since the anterior cranial base, SN, was to be used for the facial analysis, it was decided to use this plane as the base for the construction of the cranial polygon. For the purposes of illustration, the cranial points were plotted relative to the SN plane. All the points used were in the midline.

Variation of the frontal region of the cranial outline was examined by superimposition on the SN plane Each age group was divided into crania with angles greater or less than the mean angle SNF for the group. The resulting mean polygons were compared and individuals showing the greatest variation used to illustrate differences in cranial form.

Mean measurements and standard deviations were also recorded from the young and adolescent age groups, then compared statistically to determine age changes.

Analysis of the facial structures and profile

Facial landmarks were located using the techniques set down by Brodie,[9] Bjork[3] and Downs.[18] These techniques are well known and need not be discussed in detail. The points used are explained in the glossary of terms and illustrated in figures 1 and 2. As in the case of the cranium, illustrations were constructed by plotting facial points to the SN plane.

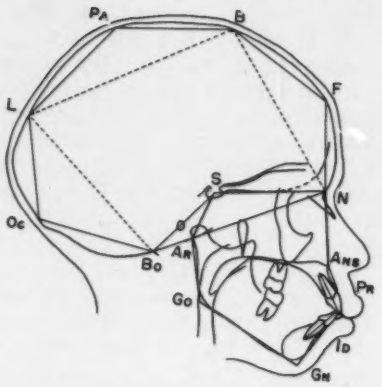

Fig. 1 The cranial polygon and Bjork's facial polygon.

Since the facial structures were to be compared with previous racial studies, the geometric form devised by Bjork[3] was employed to examine the face. As pointed out by Bjork, this polygon showed the effects on the profile of varying facial structures and the cranial base. In addition, the lengths of the maxillary (Ptm to Ans) and mandibular (Go to Po) bases were expressed as proportions of the anterior cranial base (SN).

The facial profile was analyzed by

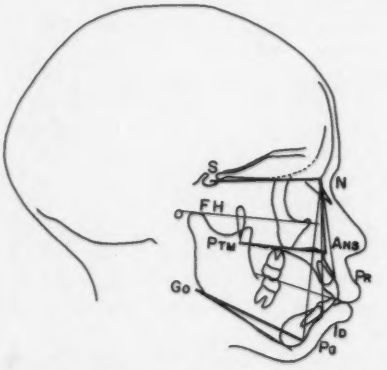

Fig. 2 The facial profile angles and the horizontal planes.

angular reading to the SN plane registered at nasion. These have been outlined by Bjork[4]:

"1. Maxillary basal prognathism: The angle formed by the cranial base and a profile line through nasion and the nasal spine.
2. Maxillary alveolar prognathism: The angle formed by the cranial base and a profile line through nasion and prosthion.
3. Mandibular alveolar prognathism: The angle formed by the cranial base and a profile line through nasion and infradentale.
4. Mandibular basal prognathism: The angle formed by the cranial base and a profile line through nasion and pogonion."

An index of the convexity of the face, the facial profile angle, was obtained by joining the points, N, A and Pg. In addition, Downs'[18] analysis of the facial profile was applied to twenty aboriginals between the ages ten years and young adult, equally divided in sex.

In order to compare the Australian aboriginal with Brodie's[9] findings in the North American white male, the angular relationships of certain horizontal planes to the anterior cranial base were measured. These consisted of the palatal plane, the occlusal plane and the mandibular plane already described by Brodie. The percentage of upper facial height (NAns) to total facial height (NGn) was calculated.

Measurements within the dental area were limited to angular readings of the maxillary first permanent molar (NS6), the edge of the central incisor (SN1), the relationship of the long axes of the upper and lower incisor teeth and the angular relationship of the lower incisor to the mandibular plane.

Variation within the Australian aboriginals was examined by deriving the means of those individuals more and less prognathic than the mean angle SNAns, in the respective age groups. As in the cranium, individual cases in each group were examined to determine whether the same structural variation was operative as that reported by Bjork.

Changes occurring with age were observed from comparison of the mean values of the young adolescent age groups. To find out whether the difference between the means in the aboriginal subdivisions was greater than that due to chance, the 't' value was calculated. The 5% level of significance was used, which meant that the value of 't' had to exceed 2.00 to be significant.

Comparison with other races

After the establishment of mean measurements and variation in the living Australian aboriginal head, the data and illustrations of the face were compared with those of Bjork in the Swede[3] and Bantu.[4] It was found necessary to compare the two age groups of aboriginals with the age groups in Bjork's studies since changes in measurements were observed between child and adolescent aboriginal.

Similarly, individual variations in the aboriginal age groups were compared with the Swede and Bantu, and the cross sectional growth changes of the facial structures compared with the findings of Bjork and Brodie.

Employing Downs' analysis of the facial profile, the selected aboriginals were compared with the American White[18] and the American Chinese, Japanese and Negro.[17]

Glossary of Terms

Cranial

B Bregma. The point of junction of the coronal and sagittal sutures.

Bo Bolton point. The deepest point in the condyloid fossa.

F The point of greatest curvature on the frontal arc from line BN.

L Lambda. The point of junction of the lambdoid suture and the sagittal suture.

N Nasion. The mid point of the fronto-nasal suture.

Oc The point of greatest curvature on the occipital outline from the line LBo.

Pa The point of greatest curvature on the parietal outline from the line BL.

S The center of sella turcica.

Basic Quadrilateral The quadrilateral constructed from the points N,B,L,Bo.

Cranial Polygon The polygon constructed from the points N,F,B,Pa,L,Oc,Bo,S.

Facial

A Subspinale. The deepest point on the contour of the alveolar projection, between the spinal point and prosthion.

Ans Anterior nasal spine.

Ar Articulare. "The point of intersection of the dorsal contours of processus articularis mandibulae and os temporale. The mid-point is used where double projection gives rise to two points," Bjork.[3] Test roentgenograms on several White skulls showed the shadow of the dorsal contour of the mandible to cross the inferior surface of the basilar portion of the occipital bone.

B Supramentale. The deepest point on the contour of the alveolar projection between infradentale and pogonion.

Gn Gnathion. The deepest point on the chin, Bjork.[3] A point on the chin half way between pogonion and menton, Brodie.[9]

Go Gonion. The point of intersection between the base and ramus tangents to the mandible. The mid point was used where double projection gave rise to two images.

Id Infradentale. The point of transition from the crown of the medial mandibular incisors to the alveolar process.

1 Maxillary central incisor.

$\overline{1}$ Mandibular central incisor.

6 Maxillary first permanent molar, the mesial contact point.

Or Orbitale. The deepest point on the left infraorbital margin.

Pg Pogonion. The most prominent point of the chin.

P Porion, (cephalometric). The mid point of the upper edge of the external acoustic meatus.

Pr Prosthion. The transition point between the crown of the most prominent medial incisor in maxilla and the alveolar projection.

Ptm Pterygomaxillary fissure. The point at which the maxillary tuberosity abuts against the pterygoid process of the sphenoid.

F-H. Frankfort Horizontal. The plane formed by the right and left poria and the left orbitale.

Palatal plane The line joining the anterior and posterior nasal spines.

Occlusal plane The line joining the bisection of the incisor overbite to the bisection of the occlusal overbite of the first permanent molars.

Mandibular plane The line tangent to the midline projection of the body of the mandible to the most inferior portion of the symphysis of the mandible.

Facial plane The line joining nasion to pogonion.

Y axis The line joining the center of sella turcica to gnathion.

Findings

Analysis of the cranial outline

In lateral view, the cranial vaults of the Australian aboriginals were long and low, as shown by the height/length index of 70.3 for the group. This overall proportion was reflected in the mean angular measurements from the basic quadrilateral and cranial polygon (Table 1, figure 3).

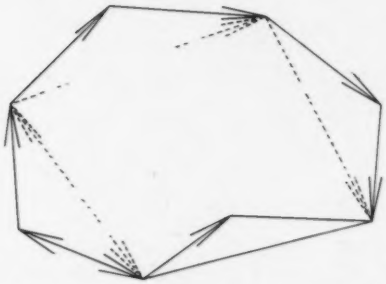

Fig. 3 The mean cranial polygon for the total group with angular ranges indicated.

Contrary to usual craniometric findings, there was little difference between the cranial outlines of the male and female. Age changes seen to occur in the cranial form were a decreased inclination and curvature of the frontal bone due to alteration at nasion (Table II, figure 4).

As was expected, variation of the angle SNF was accompanied by variation of the remainder of the cranial outline. Unfortunately, the number of aboriginals in each subdivision of the age groups was too small to permit statistical evidence of correlation between various angles. The study of the extreme variants, in each age group, showed changes in the cranial base, namely, increased length SN and decreased cranial base angle, BoSN, with the more recessive forehead. Indeed, the cranial outline of this type of individual appeared displaced backward relative to the plane of orientation, SN. (Table III).

Using Schwalbe's[34] analysis of the cranial outline, Berry and Robertson[1] have reported on the Australian aboriginal, while Slome[35] has examined the Bushman. The present adaptation of Wilder's[39] cranial analysis has only one angle in common with Schwalbe's method, the angle of parietal curvature, BPaL. This curvature, according to Berry and Robertson[1], has a mean value of 135.7° in the adult aboriginal and a mean measurement of 129° in the European. Slome's measurement of parietal curvature, (mean 135.6°), in the adult Bantu, was similar to that reported in the aboriginal. In the present study, the group of aboriginal children and adolescents showed a mean measurement of parietal curvature of 131°. The finding of a low standard deviation for this angle, BPaL, confirmed Slome's observation that the parietal curvature varied within narrow limits.

Fig. 4 The mean cranial and facial polygons of the aboriginal child and adolescent. (Superposed on the SN plane and registered at S.)

TABLE I

The Proportional and Angular Readings of the Cranium for the Total Group and the Male and Female Subdivisions

	Total Group (51)			*Male (20)*			*Female (31)*			*'t'**
	Mean	*Range*	*S.D.*	*Mean*	*Range*	*S.D.*	*Mean*	*Range*	*S.D.*	
Proportion										
Height/length	70.3	67 — 79	2.23	71.0	68 — 75	1.95	69.96	67 — 79	2.21	1.38
Angles										
Basic quadrilat.										
BoNB	76.7	71 — 83	2.72	78.0	72.5— 83	2.8	76.0	71 — 81	2.2	1.42
BLBo	71.8	66.5— 80	2.83	71.0	67 — 76	2.3	72.0	66.5— 80	3.12	1.13
NBL	98.5	90 —106	3.57	98.0	90 —102.5	3.6	99.0	91 —106	3.52	1.26
LBoN	112.9	104 —121	4.19	113.17	106 —120	4.55	112.77	104 —121	4.29	0.33
Cranial Polygon										
SNF	92.0	84 —100	3.83	92.05	86 — 99	3.85	91.85	84 —100	3.88	0.18
NFB	124	116 —135	3.93	124.27	116 —135	4.68	123.64	116.5—129	3.42	0.55
FBPa	146	140 —155	3.36	145.5	140 —155	3.91	146.5	140 —151	2.95	1.04
BPaL	131	124 —137.5	2.71	129.7	124 —134.5	2.82	131.7	128 —137.5	2.35	2.73
PaLOc	131	122 —141	4.89	129.1	123 —141	5.17	132	122 —140	4.47	1.97
LOcBo	115.5	106.5—128	4.76	116.97	110 —127.5	4.23	114.61	106.5—128	4.55	1.92
OcBoS	122	111 —132.5	5.12	122.35	113 —131	5.55	121.4	111 —132.5	4.88	0.69
Cranial base										
BoSN	142	127 —152	4.74	141.04	127 —147.5	4.51	142.82	131 —152	4.8	1.13
Length S-N	61.75	54 — 71.1	3.62	61.54	54 — 66.6	3.74	61.88	54.9— 71.1	3.59	0.33

*The 5% level of signficance of 't' is 2.00.

TABLE II

The Proportional and Angular Readings of the Cranium for the Child and Adolescent Groups

	Child (27)			*Adolescent (29)*			*'t'**
	Mean	*Range*	*S.D.*	*Mean*	*Range*	*S.D.*	
Proportion							
Height/length ..	70.76	67 - 79	2.52	69.92	67 - 74.5	1.83	1.60
Angles							
Basic quadrilat.							
BoNB	77.8	71 - 83	3.05	75.76	72.5- 78.5	1.81	2.89
BLBo	71.4	66.5- 80	3.11	72.02	67 - 77	2.53	0.78
NBL	97.55	90 -104.5	3.70	99.60	93 -106	3.17	2.12
LBoN	113.23	104 -121	4.56	112.62	107.5-120	3.85	0.54
Cranial polygon							
SNF	93.46	84 -100	3.57	90.34	84 - 98	3.50	3.15
NFB	122.96	116.5-130	3.13	124.88	116 -135	3.85	1.93
FBPa	145.5	140 -150	3.26	146.78	142 -155	3.39	1.37
BPaL	130.4	124 -135	2.51	131.5	125.5-137.5	2.84	1.46
PaLOc	130.11	123 -140	4.41	131.44	122 -141	5.35	0.97
LOcBo	115.9	106.5-127.5	4.64	115.12	106.5-128	4.50	0.48
OcBoS	122.94	115 -132.5	5.31	120.65	111 -128.5	4.76	1.70
Cranial base							
BoSN	142.72	133 -152	4.68	141.7	127 -150	4.83	0.80
Length S-N	59.29	54 - 64.8	2.79	63.93	56.7- 71.1	2.77	6.20

*The 5% level of significance of 't' is 2.00.

Analysis of the facial structures and profile

The mean values, ranges and standard deviations of measurements from the facial structures and profile are recorded in Table IV. It was interesting that the mean percentage of upper facial height to total facial height

TABLE III

The Proportional and Angular Measurements of Individuals Exhibiting Variation in the Cranial Outline.

	Child		*Adolescent*	
	No. 45 F 11 yrs.	*No. 41 F 11 yrs.*	*No. 29 F Ad.*	*No. 56 F Ad.*
Proportion				
Height/length	69	71	68	71
Angles				
Basic quadrilat.				
BoNB	71	80	73.5	76
BLBo	71	75.5	73	75
NBL	101.5	97	103	95
LBoN	116.5	107.5	110.5	114
Cranial polygon				
SNF	84	100	84	96
NFB	125	122	129	125
FBPa	149	145	150	142.5
BPaL	131.5	131	134	133.5
PaLOc	125	136	136.5	127.5
LOcBo	116	111	106.5	118
OcBoS	126	127	123.5	127.5
Cranial base				
BoSN	138	152	142	149
Length S-N (mm)	63	55.8	63	63

TABLE IV

The Proportional and Angular Readings of the Facial Analysis of the Australian aboriginals.

	Total Group (56)			*Male (21)*			*Female (35)*			*'t'**
	Mean	*Range*	*S.D.*	*Mean*	*Range*	*S.D.*	*Mean*	*Range*	*S.D.*	
Angles										
Bjork's polygon										
NSAr	118.6	101.5—130.5	5.51	116.7	101.5—125	5.80	119.9	101.5—130.5	5.11	1.90
SArGO	149.13	130 —168.5	8.42	150.38	130 —168	9.64	148.38	133 —168.5	9.98	0.85
ArGoGn	123.25	104 —137	6.93	124.35	105 —135	7.08	122.82	104 —137	6.59	0.81
GoGnId	87.37	76 — 99.5	5.14	86.55	76 — 95.5	4.37	87.88	77 — 99.5	5.83	0.89
SNAns	86.82	76 — 96.5	3.94	86.64	78 — 95	3.66	86.92	76 — 96.5	4.32	0.25
NAnsPr	158.17	141.5—172	7.13	159.9	148 —172	6.4	157.1	141 —170.5	7.40	1.43
Facial Profile										
SNAns	86.82	76 — 96.5	3.94	86.64	78 — 95	3.66	86.92	76 — 96.5	4.32	0.25
SNPr	93.32	83 —104.5	4.0	92.19	85 — 98.5	3.40	94	83 —104.5	4.21	1.66
SNId	87.59	79.5— 95	3.58	87.16	80 — 94	3.36	87.84	79.5— 95	3.75	0.68
SNPg	82.18	74 — 91.5	3.63	81.88	77 — 91.5	3,56	82.37	74 — 88.5	3.70	0.48
NAPg	171.21	159.5—186	6.32	171.45	161.5—183.5	6.10	171.07	159.5—186	6.53	0.22
Horizontal planes										
Palatal plane	7.1	0 — 20	3.19	6.23	2 — 10.5	2.62	7.61	0 — 20	3.42	1.58
Occlusal plane	16.06	7 — 26	4.27	15.78	7 — 23	4.52	16.52	7 — 26	3.85	0.62
Mandibular pl.	31.60	16 — 44	5.69	32.5	17 — 42	5.68	31.07	16 — 44	5.69	0.91
Denture										
Interincisal	115.34	97 —137	8.36	117.02	100.5—134.5	7.91	114.32	97 —137	8.57	1.17
1 to Mand. pl.	103.11	90 —122	6.11	101.59	90 —110	5.11	104.02	90.5—122	6.54	1.45
NS6	56.5	47.5— 63	3.55	57.5	47.5— 63	3.67	55.8	48 — 63	3.31	1.73
SN $\bar{1}$	92.4	82 —104.5	4.22	91.4	82 — 98	4.05	93	83.5—104.5	4.25	1.41
Proportions										
Horizontal										
Maxilla	73.57	66.1— 82.5	4.06	72.50	86.1— 81	3.50	74.2	63 — 82.5	4.23	1.34
Mandibular	110.30	97.1—123.5	6.29	108.69	97.1—1[illegible]	6.75	111.3	98.3—123.5	6.11	1.34
Vertical										
Upper face	43.24	39 — 48	1.91	42.85	39 — 46.5	1.83	43.82	41 — 48	1.87	0.72
Length SN	61.75	54 — 71.1	3.62	61.54	54 — 66.6	3.74	61.88	54.9— 71.1	3.59	0.33

*The 5% level of significance of 't' is 2.00.

43.24%, was in accord with previous observations in many racial groups.[22]

As in the case of the cranium, there was no significant difference between male and female facial measurements. However, the "saddle angle " (NSAr) approached the level of significance, the female cranial base being more obtuse than the male. This finding tended to confirm the work of Cameron[14] who has shown the cranial base of the American White female to be flatter than the male and that the same condition obtained in the American Negro.

Employing the standard deviation as an index of variability, the "joint angle", SArGo, was found most variable and the angle of the palatal plane to SN least variable. The palatal, occlusal and mandibular planes showed an increase in variability as the distance from SN increased, as has been reported in previous studies.

Variability of the facial profile angles, using the standard deviation as a criterion, was less than the variability of those facial structures which have been held to determine the profile (Table IV). This finding agreed with Pearson and Davin[32] who showed that variability of the cranium was less than that of the component parts; agreed, also, with Bjork[3] who believed the combination of variables may result in a cancelling out of the factors which lead to excessive prognathism.

Examination of the mean values for the more prognathic and less prognathic groups in each age subdivision showed that the chief factors in the production of the degree of facial prognathism were changes in the anterior cranial base length and the "saddle angle". A short anterior cranial base length and an acute "saddle angle" were associated with a more prognathic face. As in the cranium, the numbers in the subdivisions of the age groups were too small to permit calculations of correlations between facial measurements.

Since a combination of the angles of the facial structures, as well as the length of the anterior cranial base, has been shown to influence the individual degree of facial prognathism in the Swede and Bantu, it was interesting to notice that individuals in each aboriginal age group showed similar combinations of variables. In the child group the individuals chosen showed the effect of an increased length of the anterior cranial base (Table V and figure 5). In common with Bjork's findings, the "saddle angle" was more acute in the prognathic individual while the palatal, occlusal and mandibular planes were more nearly parallel to the SN plane. It was noticed that the degree of alveolar prognathism was less in the individual with greater total facial prognathism. Together with this reduction there was an increase in the interincisal angle.

Comparison of the individuals with greatest variation in the adolescent group showed the effects on the profile of a decreased jaw angle and a proportional increase in the length of the body of the mandible and maxilla (Table V and Figure 6). Although the anterior cranial base length was similar in each face, the reduction of the jaw angle and the relatively greater length of the maxilla and mandible have resulted in a more prognathic profile. Together with the increase in total face prognathism there has been a reduction in anterior facial height and the convexity of the profile.

Comparison of the mean facial polygons of the child and adolescent aboriginal groups revealed only slight differences. With the exception of the

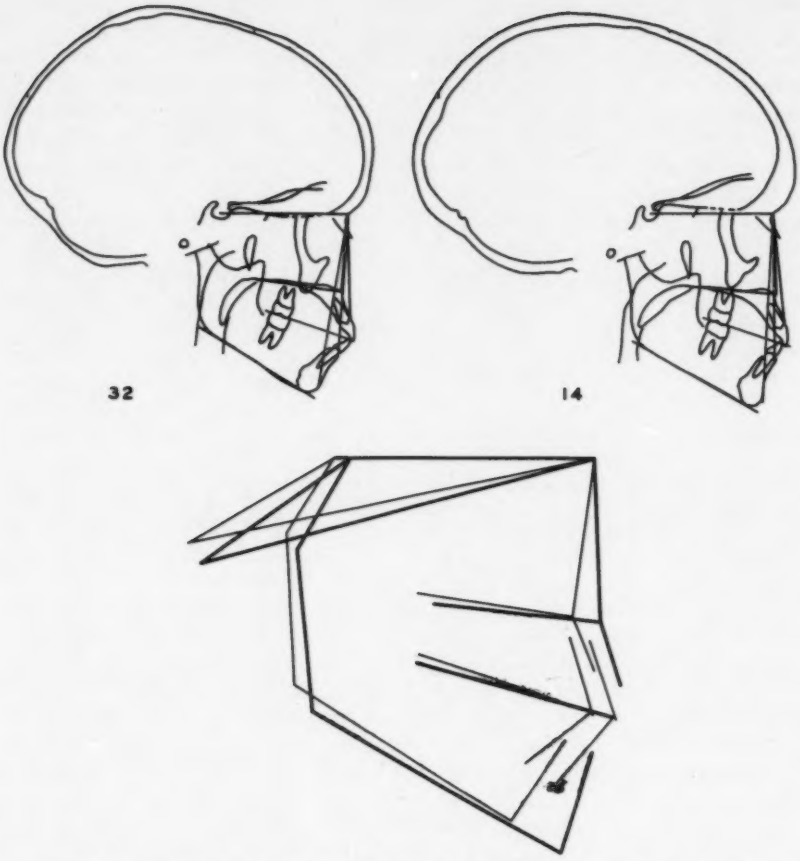

Fig. 5 Individual variation of the facial pattern in the aboriginal child.

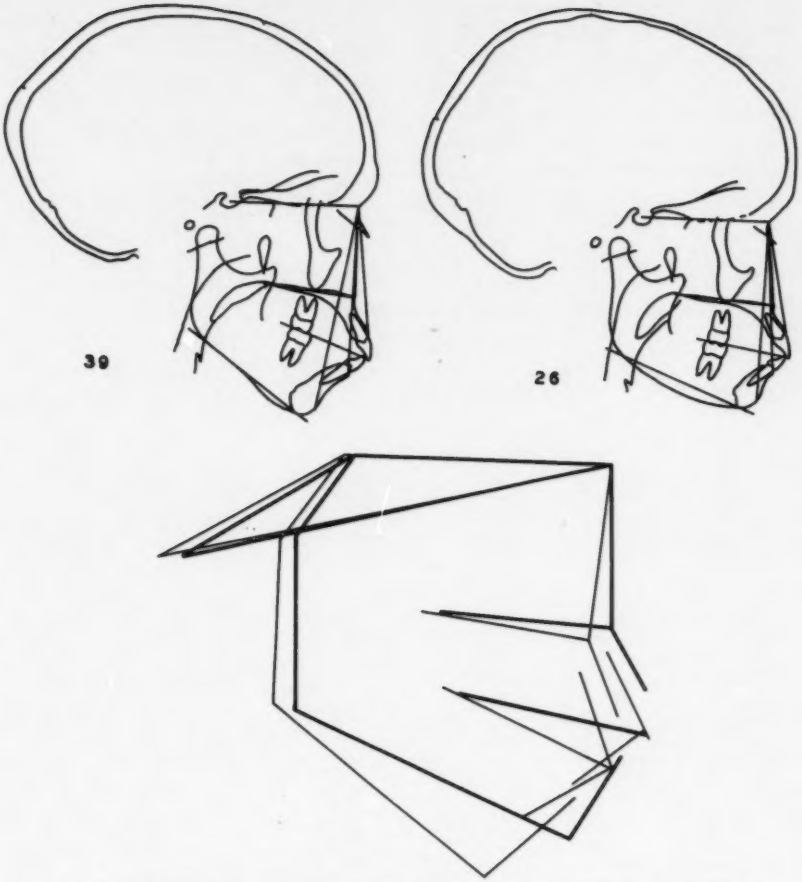

Fig. 6 Individual variation of the facial pattern in the adolescent aboriginal.

amount of maxillary alveolar prognathism, NAnsPr, there were no highly statistically significant differences (Table VI and figure 4).

Age changes were noticed in the profile, (Figure 7). Although a statistically significant difference was recorded for the increase in the degree of mandibular alveolar prognathism, this may have been of an additive nature, i.e. mandibular basal increase plus alveolar increase. As the degree of maxillary basal prognathism showed very little increase, it was not surprising to find a reduction of facial convexity with increased age. This was also seen in the decrease in proportional length of the maxilla and the increase in mandibular proportional length. These findings conform with most studies of the growing human face.

Surprisingly, the long axes of the lower incisors showed an increase in procumbency with age. Since there was a decrease in the interincisal angle, the maxillary incisors also increased in procumbency.

Comparison with other races

TABLE V

The Proportional and Angular Measurements of Individual Cases Exhibiting Differences of Maxillary Basal Prognathism

	Child		*Adolescent*	
	No. 14 F 9 yrs.	*No. 32 F 8 yrs.*	*No. 26 F 15 yrs.*	*No. 39 F 15 yrs.*
Angles				
Bjork's polygon				
NSAr	119.5	121	125	123
SArGo	145	150	144	147
ArGoGn	125	124	114	126.5
GoGnId	77	91.5	96	96.5
SNAns	92.5	84	92.5	87
NAnsPr	167.5	158	153	155.5
Facial profile				
SNAns	92.5	84	92.5	87
SNPr	96	90.5	101.5	94
SNId	90	83	94	87
SNPg	87	78	88	78
NAPg	169	168.5	170	165
Horizontal planes				
Palatal plane	6	9	2.5	7.5
Occlusal plane	17	21.5	10	22
Mandibular plane	30	35	23	37
Denture				
Interincisal	121	113	104	101
1 to Mand. pl.	98.5	107	116	110
$NS\underline{6}$	56	57	54	57
$SN\underline{1}$	94.5	90	100	94
Proportions				
Horizontal				
Maxilla	73.8	70.5	76.4	71.4
Mandible	116.9	104.4	123.5	110
Vertical				
Upper face	42.7	42.8	44	43.1
Length SN (mm)	58.5	61.2	61.2	63
Facial angle	91	89	100	90
Cranial base angle, BoSN	145	150	148	150

TABLE VI

The Proportional and Angular Readings of the Face of the Young and Adolescent Australian aboriginals.

	Young (27)			*Adolescent (29)*			*'t'**
	Mean	*Range*	*S.D.*	*Mean*	*Range*	*S.D.*	
Angles							
Bjork's polygon							
NSAr	117.51	101.5—130.5	6.07	119.82	106.5—128	4.67	1.60
SArGo	150	130 —168	8.23	148.33	133 —163.5	8.66	0.73
ArGoGn	124.81	111.5—137	5.98	122.08	104 —133	7.26	1.53
GoGnId	86.7	77 — 97	4.78	88.01	81.5— 99.5	5.79	1.55
SNAns	86.79	76.0— 95.0	3.68	86.84	78.0— 96.5	4.44	0.04
NAnsPR	162.0	152.0—172.0	6.64	154.60	141.5—165.0	5.61	4.51
Facial profile							
SNAns	86.79	75.0— 95.0	3.68	86.84	78.0— 96.5	4.44	0.04
SNPr	92.33	85.5— 98.5	3.96	94.24	85.0—104.5	3.86	1.82
SNId	86.41	79.5— 92.0	3.27	88.68	80.0— 95.0	3.58	2.47
SNPg	81.31	76.5— 87.5	3.35	83.0	77.0— 91.5	3.73	1.78
NAPg	170.35	169.5—180	5.69	172.24	162.5—186	6.79	1.13
Horizontal planes							
Palatal plane	7.2	2.0— 20.0	3.80	6.98	0.0— 12.0	2.57	0.25
Occlusal plane	17.72	12.0— 26.0	3.62	14.51	7.0— 23.0	4.30	3.00
Mandibular plane	33.13	25.0— 44.0	4.38	30.19	16.0— 42.0	6.42	1.98
Denture							
Interincisal	116.92	104.0—137.0	7.92	113.86	101.0—131.5	8.63	1.38
1 to Mand. pl.	100.79	90.5—110.0	4.75	105.27	90.0—122.0	6.51	2.92
$NS_{\underline{6}}$	57.7	52 — 63	2.86	55.22	48 — 60.5	3.67	2.85
$SN_{\underline{1}}$	91.54	83.5— 98	3.61	93.29	82 —104.5	4.55	1.47
Proportions							
Horizontal							
Maxilla	74.0	68.1— 81.7	3.68	73.19	63.0— 82.5	4.29	0.67
Mandibular	108.14	97.1—121.7	6.28	112.32	102.7—123.5	5.79	2.36
Vertical							
Upper face	43.09	39.0— 46.0	1.60	43.80	41.0— 48.0	2.06	0.24

*The 5% level of significance of 't' is 2.00.

Mean facial measurements of the Swede[3] and Australian aboriginal are shown in Table VII and illustrated, together with Bjork's mean polygon for the Bantu,[4] in figures 8 and 9. Comparison of these figures showed inter-racial differences in the facial structures, as determined by Bjork's polygon. The Australian aboriginal showed the most acute "saddle angle", NSAr, together with the most obtuse "joint angle", SArGo. As would be expected, the "chin angle", GoGnId, was greatest in the aboriginal. The Bantu and aboriginal mandibles appeared to have a similar form, contrasting with the wider "jaw angle" of the Swede.

Despite inter-racial differences of

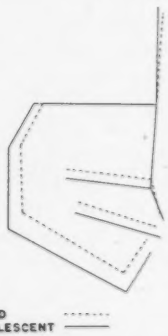

Fig. 7 The mean facial patterns of the child and adolescent aboriginal. (Superposed on the SN plane and registered at N.)

TABLE VII

Comparison of the Findings Obtained in the Swede by Bjork (1947) with the Findings Obtained in the Australian Aboriginal

	Child				*Adult*		*Adolescent*	
	Swede		*Aboriginal*		*Swede*		*Aboriginal*	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Angles								
Bjork's polygon								
NSAr 122.9	4.85		117.5	6.07	123.06	5.33	119.8	4.67
SArGO 142.96	6.21		150.0	8.23	143.27	6.91	148.33	8.66
ArGoGn 131.09	6.11		124.81	5.98	130.85	7.31	122.08	7.26
GoGnId 68.58	5.4		86.7	4.78	64.24	6.43	88.0	5.79
SNAns 85.77	3.83		86.79	3.68	88.16	4.18	86.84	4.44
Facial profile								
SNAns 85.77	3.83		86.79	3.68	88.16	4.18	86.84	4.44
SNPr 83.68	3.67		92.33	3.96	84.83	4.13	94.24	3.86
SNId 80.01	3.66		86.41	3.27	82.25	4.37	88.68	3.58
SNPg 78.92	3.63		81.31	3.35	81.69	4.43	83.0	3.73
NAPg 173.90	5.27		170.35	5.69	177.02	6.96	172.24	6.79
Horizontal planes								
Palatal plane 7.77*			7.2	3.80	7.82*		6.98	2.57
Occlusal pl. . 19.43*			17.72	3.62	16.34*		14.51	3.00
Mandib'r pl. 36.98*			33.13	4.38	36.53*		30.19	6.42
Denture								
Interincisal .128.45	8.80		116.92	7.92	137.44	11.76	113.86	8.63
Proportions								
Horizontal								
Maxilla 75.18*			74.0	3.68	77.63*		73.19	4.29
Mandible ...106.2	5.85		108.14	6.28	110.3	7.14	112.32	5.79
Vertical								
Upper face.. 44.26*			43.09	1.6	43.22*		43.80	2.0
Length SN ... 68.76mm	2.97		52.29mm	2.79	73.22mm	3.26	63.93mm	2.77

*Calculated from Bjork's data.

the facial structures, the profiles of the three races showed similarities. The degree of alveolar prognathism was highest in the Australian aboriginal, while maxillary and mandibular basal prognathism did not differ greatly. This was especially evident in the degree of maxillary basal prognathism (SNAns) and the parallelism of the palatal planes.

Dental measurements showed the incisors to be most procumbent in the aboriginal and least procumbent in the Swede. The mean interincisal angle of the adult Swede was 137° with a range of 70°, the mean of the Bantu 120°, with a range of 55°, while the mean of the aboriginal was 113.8° with a range of only 30.5°. However, this small range may be due to the size of the sample.

Both child and adolescent or adult groups showed similar racial differences: but it was noticed that maxillary basal prognathism was slightly greater in the aboriginal child than the Swedish boy, a condition reversed in the adult.

Comparison of the selected group of Australian aboriginals with the American White, American Negro, American Chinese and Nisei,[17 18] showed the mean values for the Downs' analysis of the aboriginal facial skeleton to be within the range of variation of the American White (Table VIII). With the exception of the inclination of the occlusal

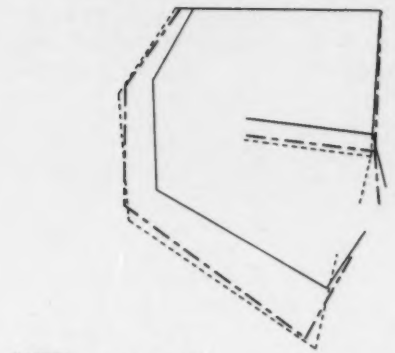

Fig. 8 Comparison of the mean facial pattern of the aboriginal child with Bjork's illustrations of the Swedish boy and twelve year old Bantu. (Superposed on the SN plane and registered at N.)

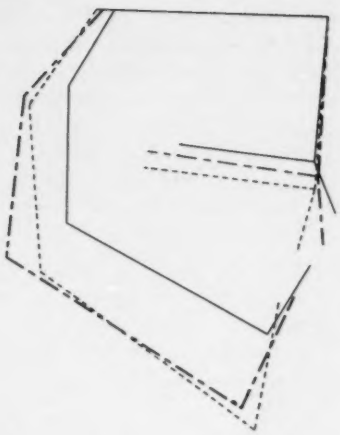

Fig. 9 Comparison of the mean facial pattern of the adolescent aboriginal with Bjork's illustrations of the adult Swede and Bantu. (Superposed on the SN plane and registered at N.)

plane to Frankfort Horizontal, the readings of the denture showed extreme dental protrusion in the aboriginal; the aboriginal facial angle was greater than

TABLE VIII

Mean Measurements and Ranges from the Downs' Analysis of the Australian Aboriginals Compared with the Findings Reported by Downs (1948), Cotton, Takano and Wong (1951).

Value	*Amer. White*	*Amer. Negro*	*Nisei*	*Austr. Aboriginal*	*Amer. Chinese*
Facial angle	87.9 82 to 95	87.25 80 to 91	88.25 83 to 94	91.5 87 to 100	77.5 73 to 89
Mandibular plane angle	21.9 17 to 28	27.25 17 to 35	24.3 14 to 33	21.9 9 to 31	32.4 22 to 44
Y - axis	59.3 53 to 66	63.3 57 to 69	62.1 56 to 68	54.5 45 to 61	67.1 59 to 75
Angle of Convexity	0.0 +10 to —8.5	+9.6 +4 to +20	3.65 +12 to —1	+8.4 0 to +17.5	+7.5 +1.5 to +14
AB plane to facial plane	—4.7 0 to —9	—7.7 —3 to —15	—4.35 —1 to —7	—2.65 —9 to +2	—5.7 —2 to —10
Cant of occlusal pl.	9.2 1.5 to 14	11.8 +8 to +17	9.65 2 to 19	7.2 —1 to +12.5	16.9 +8 to +25
$\underline{1}$ to $\overline{1}$ ..... (interincisal)	135.4 130 to 150.5	123.0 105 to 144	126.4 114 to 152	114.5 100.5 to —129.5	120.8 105 to 137
$\overline{1}$ to occl. pl.	14.5 3.5 to 20	22.5 12 to 35	21.5 8 to 31	29.1 21.5 to 40	22.2 13 to 29
$\overline{1}$ to mand. pl. ..	1.5 —8.5 to +7	+6.6 —3.5 to +22	+6.55 —6 to +13	+14.1 +1.5 to +31	7.8 0 to +18
$\underline{1}$ to AP pl. ..... (mm.)	3.1 —1 to 5	8.5 6 to 11	6.6 2 to 10	10.9 7 to 14	7.6 3 to 12

any of the four ethnic groups.

When the standard deviation was taken as an indication of variability, similar variation of the angles and proportions of the face to those of the Swede[3] were found in the Australian aboriginal. As has already been pointed out, individual variation in the aboriginal was the same as that reported by Bjork in the Swede and Bantu.

It was interesting to note that in both Swede and aboriginal variability of the facial angles to the SN plane was greater than to the Frankfort Horizontal.

Growth in length of the anterior cranial bases of the Swede and aboriginal was similar (Table VII). Despite this almost equal increment, the proportional length of the maxillary base of the aboriginal decreased with age, while that of the Swede increased. This was reflected in the different measurements of maxillary basal prognathism. Although mandibular basal prognathism increased with age in both Swede and Bantu, the decrease in chin angle reported by Bjork did not occur in the aboriginals who showed an increase in this measurement.

The inclination of the palatal planes of both Swede and aboriginal remained almost the same with advancing age, but the occlusal and mandibular planes showed a tendency to become parallel to the SN plane.

Both Bjork[3] and Brodie[10] have stated that with age the basal prognathism of the jaws increases beyond alveolar prognathism. In the Australian aboriginal alveolar prognathism increased beyond basal prognathism especially in the maxilla. Accompanying the increased alveolar prognathism of the aboriginal the incisors became more procumbent. Thus, in the Swede the interincisal angle increased with age, while the aboriginal interincisal angle decreased.

Discussion

The Frankfort Agreement of Anthropologists adopted the following classifications for length/height indices of the skull:

Below 70.0	chamae-cephalic or low headed
70.1 to 75.0	ortho-cephalic
above 75.1	hypsi - cephalic or high headed.

Thus, the Australian aboriginals in the present study are almost in the low headed group. Although this finding differs from the observations of Campbell, Gray and Hackett, who described the living Central Australian aboriginal as hypsi-cephalic, it is possible that the differences are due to the methods employed. But, if we accept Birdsell's surmise that this group is a mixture of Murrayian and Carpentarian elements, the former with a long, low and narrow cranial vault, low headedness may be readily explained.

It would appear, on the basis of the parietal curvature, that Klaatsch's[26] idea of determining racial specialization from the components of the cranial outline is not valid. However, the application of a geometric form, such as that of Wilder,[39] to radiographic cephalometry seems to hold promise, especially now that basion, or a point close to it, can be determined in some radiographs.[5] Perhaps cranial form influences the cranial base, which in turn may modify the relationships of facial structures; so that a dolico-cephalic skull is associated with a flat cranial base and the requisite compensations in mandibular form. The changes in skull outline with the variation in inclination of the forehead seem to indicate such a possibility.

Although the radiographic cranial polygon is independent of certain sexual

characteristics of the skull, e.g. the glabella, it still relies on nasion for the anterior limit of the cranial base. Since nasion is part of the face and closely associated with the supraorbital ridges, it has an independent growth relative to other cranial landmarks. Thus, some of the variation and growth changes in the inclination of the forehead can be explained on the behaviour of nasion. Bjork has observed this increased recession of the forehead with age in the Bantu and Swede.[5] It would appear that the similarity between growth of the aboriginal cranial outline and those of other primates reported by Krogman[27] is also due to the changes at nasion.

The close approximation of male and female cranial outlines may be due to the method employed and the age distribution; within the group there were greater numbers of young boys and older girls. This age distribution may also explain the almost significant difference between male and female cranial base (NSAr). In view of the work of Cameron,[14] it would appear that sex differences in the cranial base do occur. Radiographic cephalometry offers an excellent means of determining this difference, but larger groups of aboriginals would be necessary.

When the anterior cranial base was used as a reference line, the facial profiles of the aboriginal, Swede and Bantu were similar; but, when measured from the Frankfort Horizontal, marked racial differences appeared. It would seem that this plane, relying on the orbital margins for its anterior termination, must be considered as a facial plane, useful for intra and inter-racial facial typing in the adult. Krogman[28] has already pointed out that the use of the F.H. in growth studies is not valid, since porion changes position with age. However, the plane has readily accessible landmarks and, in the case of the North American White, closely approaches the normal posture of the head.[19] Whether the F.H. is also representative of head posture in other racial groups is debatable. Studies on the position of foramen magnum[5 38] suggest that there are differences.

Although the sella-nasion plane has limitations, especially the possibility of directional growth at nasion, it appears a satisfactory plane for examining the relationship of face to cranium.

The dependence of the upper face on the anterior cranial base may be a factor in determining the degree of maxillary prognathism when using nasion as a reference point. Even so, maxillary measurements in all three racial groups suggested a uniformity of the upper face which may be characteristic of Homo sapiens. This suggestion would seem to be confirmed by the observation that the proportion of upper facial height to total facial height is similar in many racial groups.[22]

Inter-racial variation was evident in the degree of mandibular basal prognathism, but none great enough to determine any characteristic racial prognathism. As Bjork has pointed out, the facial structures producing this prognathism seem to offer a means of determining variation. In this respect, the "joint angle" is significant. Bjork has described the wide "joint angle" of the Bantu as a primitive characteristic. Thus, the Australian aboriginal may be classified as primitive; but the "saddle angle", more acute than the Swede, would seem evidence for a more advanced skull form. Perhaps, racial classification cannot be based on any single measurement. Many of the differences of proportions and angles, in comparison of the adolescent aboriginal adult Swede and Bantu, may have been due to the difference in age between the three groups.

A distinguishing feature of the Aus-

tralian aboriginal was the pronounced degree of alveolar prognathism, an observation made by many investigators. There may be three possible explanations for this prognathism: firstly, the dental arch, described by Campbell as "probably larger than any other living race", cannot be accommodated within the proportionately smaller facial structures, resulting in dental and alveolar prognathism. This would also account for the greater degree of alveolar prognathism observed in the female.

Secondly, the labial musculature of the Australian aboriginal is characterized by the extension of quadratus labii superioris and quadratus labii inferioris to the vermillion borders of the lips.[13] This arrangement of the musculature may not act as a restraining influence to the forward movement of the denture described by Brodie.[8] The hypothesis may be offered that the refinement of neuro-muscular control of the labial musculature of the white race[23] has resulted in the more upright position of the incisors and alveolar processes.

Thirdly, the early loss of cusps may permit excessive mesial movement of the dental arches together with an increased procumbency of the incisors. This may be especially so in the maxilla which, by increased procumbency of the incisors, maintains an incisor relationship despite a maxillary base relatively shorter than the mandibular base.

The convexity of the face of the Swede, Bantu and Australian aboriginal, when measured from the profile angle, differed from the interpretation gained from angular readings to points on the profile. This can be explained by the variation in length of the anterior nasal spine. As has been pointed out previously, this spine is very short in the aboriginal. The use of subspinale, A, as the anterior end of the maxilla may give a more accurate indication of maxillary prognathism. When measured from point A, the American Negro has a more convex face than the aboriginal group, which may lend some support to the observation that certain African tribes exceed the Australian in upper face prognathism.

Although variation in facial structures and profile in the three racial groups may be due to the landmarks employed, the finding of similar individual variation suggests the presence of a common genetic influence. Schultz[33] has already pointed out that, "man's range of individual variations has not yet become entirely separate from corresponding ranges in other primates".

Comparison of Australian aboriginal growth with the other races studied gave the impression that the middle face of the aboriginal completed its forward growth earlier than the cranial super-structure, nasion, or the mandible. This was an exaggeration of the previous findings that the profile becomes less convex with age. The increase in maxillary alveolar prognathism, angle NAnsPr, may be due to an adaptation of the maxillary denture to a greater forward growth of the mandible and its dental arch. Bjork believed this difference in behaviour of the dental bases was responsible for the reduction of overbite of the incisors. Similar reasoning might well explain the high incidence of edge-to-edge incisor relationship reported by Turner[37] in the adult Australian aboriginal. That the entire maxillary denture moves forward during growth is suggested by the reduction of angular readings to the first permanent molar, NS6.

The forward migration of the dentition might well explain the finding that the "chin angle" of the aboriginal does not decrease with age, as occurs

in the Swede. Likewise, the decrease in interincisal angle with age may be due to the forward movement of the dentition associated with the peculiar labial musculature of the aboriginal.

Conclusions

1. The adaptation of Wilder's analysis to radiographic cephalometry offers the possibility of understanding variations in cranial outline. In the Australian aboriginal the least variable portion of the cranial outline is the parietal region.
2. Age changes in the cranial outline occurred to a greater extent in the anterior portion and depended on the increased length of the anterior cranial base, SN.
3. Bjork's observation, that while the degree of facial prognathism is similar the nature of inter-racial facial prognathism differs, is apparent in the comparison of the Australian aboriginal with other races.
4. Inter-racial variation in the degree of middle face prognathism and the inclination of the palatal plane is less than other facial measurements.
5. The Australian aboriginal has a greater degree of alveolar prognathism than the Swede or Bantu.
6. Individual variation among the Australian aboriginals is of the same nature as that reported in the Swede and Bantu.
7. Growth changes in the Australian aboriginal facial profile are similar to those of the North American White, Swede and Bantu.
8. In contrast to the North American White, Swede and Bantu, alveolar prognathism in the Australian aboriginal increases with age.

Summary

The availability of a series of fifty-six lateral cephalometric radiographs of Central Australian aboriginals has permitted the comparison of their facial and cranial structures with those of other living races.

Following the suggestions of Wilder, the lateral view of the cranial outline was analyzed by a geometric construction based on established craniometric landmarks. For the purpose of comparing the Australian aboriginal with the Swede and Bantu, Bjork's analysis of the face was employed.

Mean values, sexual differences and age changes were determined in both cranium and face of the aboriginal. Inter-racial variation was studied and individual variations of the face and cranium examined. Since the aboriginals were divided into two age groups, differing in mean values, the adolescent aboriginals (average age about fifteen years) were compared with the adult Swede and Bantu, while the aboriginal children (average age seven and a half years) were compared with the Swedish and Bantu boys. Thus, inter-racial variation was determined.

A characteristic geometrical form was obtained from the cranial outline in which variation of the frontal region appeared related to the length of the anterior cranial base. Age changes in the cranium showed an increased recession of the forehead. Neither cranial nor facial analyses showed significant sexual differences.

Intra-racial variation among the Australian aboriginal faces was seen to depend on the length of the anterior cranial base and differences in the facial structures. Individual variation was of the same nature as that reported in the Swede and Bantu.

Although age changes in the facial profile of the aboriginal were similar to those reported in other races, there was a significant increase in alveolar prognathism, together with a decrease in the inter-incisal angle.

When the mean facial profiles of the aboriginal, Swede and Bantu were compared by superimposition on the SN plane, there was little difference in facial prognathism. However, Downs' analysis applied to the aboriginal profile and compared with other ethnic groups showed the effects of inter-racial comparison using the Frankfort Horizontal plane. The aboriginal was the most prognathic.

Characteristic of the Australian aboriginal was the pronounced alveolar prognathism, greater than the Bantu.

ACKNOWLEDGMENTS

The author wishes to acknowledge his indebtedness to Mr. John Heath, Melbourne, Australia, who very kindly permitted examination and duplication of his cephalometric radiographs of the Central Australian aboriginals.

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The Congenitally Absent Premolar Problem

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The congenital absence of one or more permanent teeth is the most common oral anomaly. Most frequently absent, exclusive of the third molars, are the second premolars especially in the mandibular arch. A solution to this problem, and one we have found practical, is space closure with appliance therapy similar to that used in cases where extractions are part of the treatment plan.

To determine the approximate incidence of missing premolars, full mouth radiographs of three hundred consecutive patients were examined. There were 124 males and 176 females in the group and the age range was seven to twenty-five years. None sought orthodontic treatment specifically for this condition and were usually unaware of it. Excluded from the series were mutilated cases and one case of partial anodontia.

Twenty persons, or 6.6 percent, had a total of 29 congenitally absent second premolars, predominantly in the mandible.

By contrast, only eight persons in this group of three hundred had a total of twelve congenitally absent maxillary lateral incisors. Since treatment was sought specifically for correction of this condition in most cases, we may presume that the percentage is even higher here than it is generally. This series indicates that second premolars are more frequently absent than lateral incisors, although the reverse is usually held to be true. Our findings are in substantial agreement with a recent survey of 3557 children, where 6.01 per cent had one or more teeth congenitally absent, with the mandibular second premolar most frequently missing followed by the maxillary lateral and central incisors.

In cases where the second deciduous molar was still present, root resorption varied from complete to none at all. In the latter cases it may be questioned whether the teeth will be retained throughout life and therefore whether treatment is indicated.

Deciduous teeth without permanent successors in any part of the mouth are rarely if ever retained beyond early adult life. "The attachment apparatus of the roots of the deciduous teeth cannot accommodate the heavier stresses of an adult jaw; hence, in deciduous teeth without successors, resorption will occur due to stresses of occlusal trauma[2]." This is particularly true in the case of the lower second deciduous molar where the large occlusal area and thin roots present an unfavorable proportion. Even were this tooth retained in an occasional case, its large mesio-distal width compared with the space normally occupied by the permanent premolar makes normal inclined plane relations impossible. Ankylosis, with an apparently "submerged" deciduous molar, is a frequent complication in these cases.

We are confronted then, with an edentulous space, or one that may soon become so in the posterior part of the mouth. The injury that may result to the occlusion and to the dental and periodontal tissues is well known and treatment becomes a necessity.

TREATMENT ALTERNATIVES

The two possible treatment plans are replacement with an artificial substitute and mechanical closure of the

space. In weighing the advantages and disadvantages of each, esthetics is fortunately not a consideration in this area as in the case of the absent maxillary lateral incisor.

The chief advantage of the "prosthetic" plan is its rapidity, in comparison with the time required for successful completion of the "orthodontic" plan. If the occlusion in other areas does not warrant treatment, it may be the plan of choice.

Retention of the deciduous molar and its replacement at the time of exfoliation is also the plan of choice in the less frequently seen malocclusions where interdental spacing is a prominent feature.

The disadvantages are:

1. A fixed bridge requires full or partial coverage of at least two abutment teeth with considerable removal of tooth structure. If little or no caries is present most patients and many dentists are reluctant to proceed.

2. It compels a young person to wear an artificial substitute for the life of his dentition. The free gingival margins in relation to teeth change throughout life, exposing the finishing lines of the castings, and the best made bridges wear or break. Such factors require remaking at intervals.

3. Crown and bridge prosthesis is an exacting phase of the general practice of dentistry. If it is decided to use a fixed bridge, Strang cautions that "the orthodontist is in a delicate ethical situation . . . . . for very often he knows that the dental practitioner, who will be called upon to make the artificial substitution, is not a competent prosthetic worker, yet he can hardly tell the parents that this is the reason for eliminating the ideal method of treatment. Such a decision, however, must be reached if the facts warrant it."[3]

Space closure with appliances avoids these disadvantages. A better result is obtained if correction of the occlusion warrants the extraction of an opposing premolar and the prospects of success are even greater if bilateral treatment is used.

A possible objection to space closure in the mandibular arch is the increase in anterior overbite where one greater than desirable already exists. This is felt to be due to mesial movement of molars, the same objection that is frequently voiced regarding premolar extraction therapy in general.[4]

This is perhaps based on the similarity of the temporomandibular joint to a simple hinge, where movement of an object toward the rotational axis (the equivalent of distal movement) results in an opening, and closing results from a forward (mesial) movement. Even if we assume such a mechanistic and oversimplified view of these structures, a few millimeters mesial movement, as in space closure, compared with the far greater distance between condyle and incisors will result in negligible overbite increase. Moreover, to consider only mesial and distal movements is to ignore the much greater roles of levelling various areas of the occlusion and of correcting axial inclinations, by means of which the overbite is corrected. Correct management of extraction cases in our experience results in a *decrease* in the original overbite.

Or the objection may be based on the observation that posterior extractions, performed for other than orthodontic purposes, frequently result in closure. This may be true in untreated cases where the teeth are permitted to drift and tilt. However, even here it has been pointed out by Bull[5] that older patients who have lost all lower posteriors, as in the frequently seen "lower lingual bar case," do not always present a deep overbite.

We can only conclude from this that the anterior overbite is the product of many complex variables in the dentofacial skeleton and masticatory

musculature. With a full-banded technique and proper appliance manipulation it is possible to finish treatment with an almost "end to end" bite, so that if a slight relapse occurs in this area, as sometimes happens, the final overbite after retention will not be excessive. It is a hasty generalization to indict this method of treatment for overclosure.

An appliance capable of root movement is essential since proper vertical axial inclinations are an objective if space closure is to be maintained. If this is neglected, Strang states, "all of these teeth are eventually going to readjust themselves to the lines of the force in action upon them. *They are going to do this by crown movement and not by root shifting* . . . . . In the premolar area the greatest relapse will be manifested by a recurrence of spacing in the extraction area."[6] This precaution is doubly applicable in view of the difficulty of maintaining proper proximal contact in the lower second premolar area.

Treatment Plan and Appliance Therapy

An analysis of the malocclusion as a whole will dictate the strategy of movement. Of particular importance are upper to lower molar relations, crowding anterior to the space, and inclination of incisors relative to basal bone.

The premolar space may be closed by the mesial movement of molars, the distal movement of premolars and canines followed by the lingual movement of incisors, or combinations of both.

Bands are placed on the first molar, first premolar, and canine. Second molars are banded if the posterior segment is desired as anchorage. If incisors are in good alignment, are not procumbent, and mesial molar movement is the objective, incisors are banded immediately. The most distal band carries an edgewise tube; other bands carry double width brackets. Siamese brackets are very efficient, but make arch manipulation slightly more difficult near the end of treatment.

Uniform tube and bracket height from cusp summits and incisal edges in the same arch is an accepted principle of edgewise technique. However, the lower first premolar bracket in most cases must be placed further gingivally than the other attachments in order to elevate this tooth. There are two reasons for this:

1. The distal marginal ridge of the premolar, due to its small lingual cusp, is low in comparison to the mesial marginal ridge of the molar.

2. The molar cusps usually show greater abrasion due to their longer period of use since eruption. Placing attachments at uniform heights will increase the discrepancy of marginal ridge heights resulting in an unsatisfactory proximal contact.

The summit of the buccal cusp of the first premolar is slightly reduced to harmonize with adjacent teeth. The above precaution will aid in attaining a better proximal contact in an area where it is frequently difficult to do so.

Successive round wire arches are placed for levelling, correcting rotations and principally for uprighting. A double round loop is incorporated in the center of the space (Fig. 1) making the action gentle in the first phases of treatment and effective over a longer period of time. The loop is activated slightly and adjustments are made at intervals of not less than four weeks.

A rectangular wire (.021 x .025) into which has been incorporated a Bull loop and tie back spur (Fig. 2) is placed next without activating the loop. Later the loop is opened one millimeter by tying back at intervals of not less than three weeks. More frequent activations result in loss of anchorage and unfavorable tissue reactions.[7]

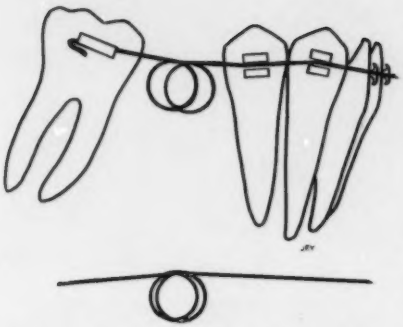

Fig. 1 Round wire arch with double loop (active) in the mouth. Below it, archwire in its passive form before insertion.

Intermaxillary elastics of the Class II or III type may be used either to aid desired movement in one segment or to prevent undesired movement in another.

When the crowns are in contact and x-rays reveal that the roots are not parallel, the molar may be given a tipback, and the premolar a tip-forward bend, while actively maintaining proximal contact.[8]

If the second molar has not been banded it will usually be found mesially inclined. A slight mesial inclination is normal and may actually help maintain proximal contacts throughout the arch. If excessive, it may be corrected by banding and uprighting.

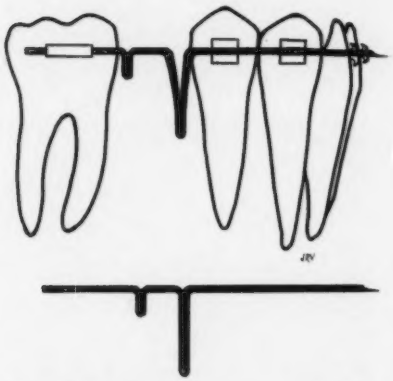

Fig. 2 Rectangular wire arch with Bull loop (active) and tie-back spur in the mouth. Below, its passive form.

Case Reports

Case 1. M. B., female, 11 years. Class II, Division 1 with moderate lower anterior crowding. Lower second premolars, right and left, were congenitally absent (Fig. 3). Brother was missing one premolar.

Lower deciduous molars and upper first premolars were extracted. Intermaxillary elastics, in addition to occipital anchorage in the upper arch, were used. Lower second premolar spaces were closed by a combination of mesial molar movement and distal premolar and canine movement. Treatment time: twenty-six months.

The lower right premolar shows distortion of its apex, and the lower left premolar, slight apical resorption (Fig. 3B).

Case 2. J. S., male, 13 years. Lower left second premolar and upper right second premolar were congenitally absent. Buds of upper left premolars were ectopic, and upper lateral incisors were undersized. The patient's father gave a history of partial anodontia.

The series of four x-rays (Fig. 4) taken over a period of three years shows the space closure and uprighting of adjacent teeth. The crowns have been moved together approximately 10 millimeters and the apices 14 millimeters.

No root resorption is evident. There is slight distortion of the premolar apex.

Case 3. B. G., female, 11 years. Class II, Division 1 bi-maxillary protrusion with moderate lower anterior crowding. Lower second premolars, right and left, were congenitally absent. (Fig. 5)

The ankylosed lower deciduous

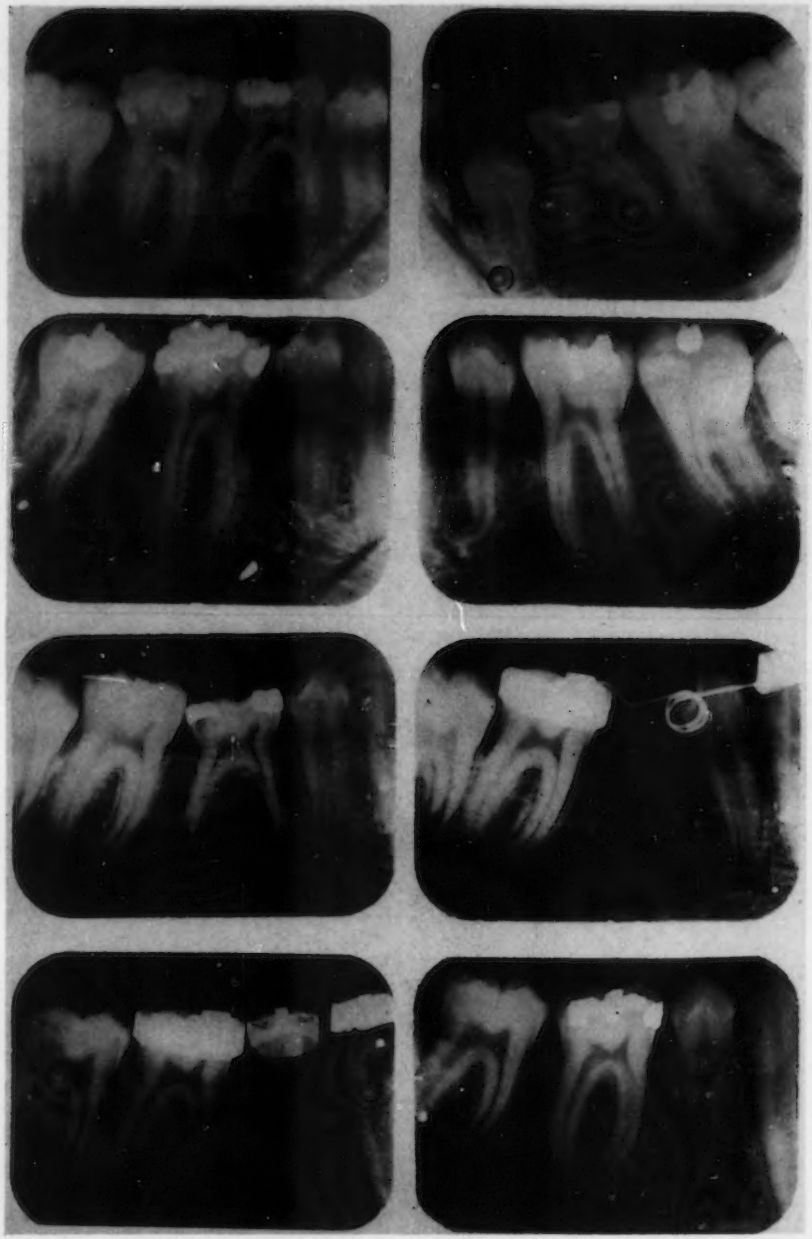

Fig. 3 Above, before treatment. Below, after treatment.
Fig. 4 Above left, pre-treatment. Above right and below left, progress x-rays. Below right, post-treatment.

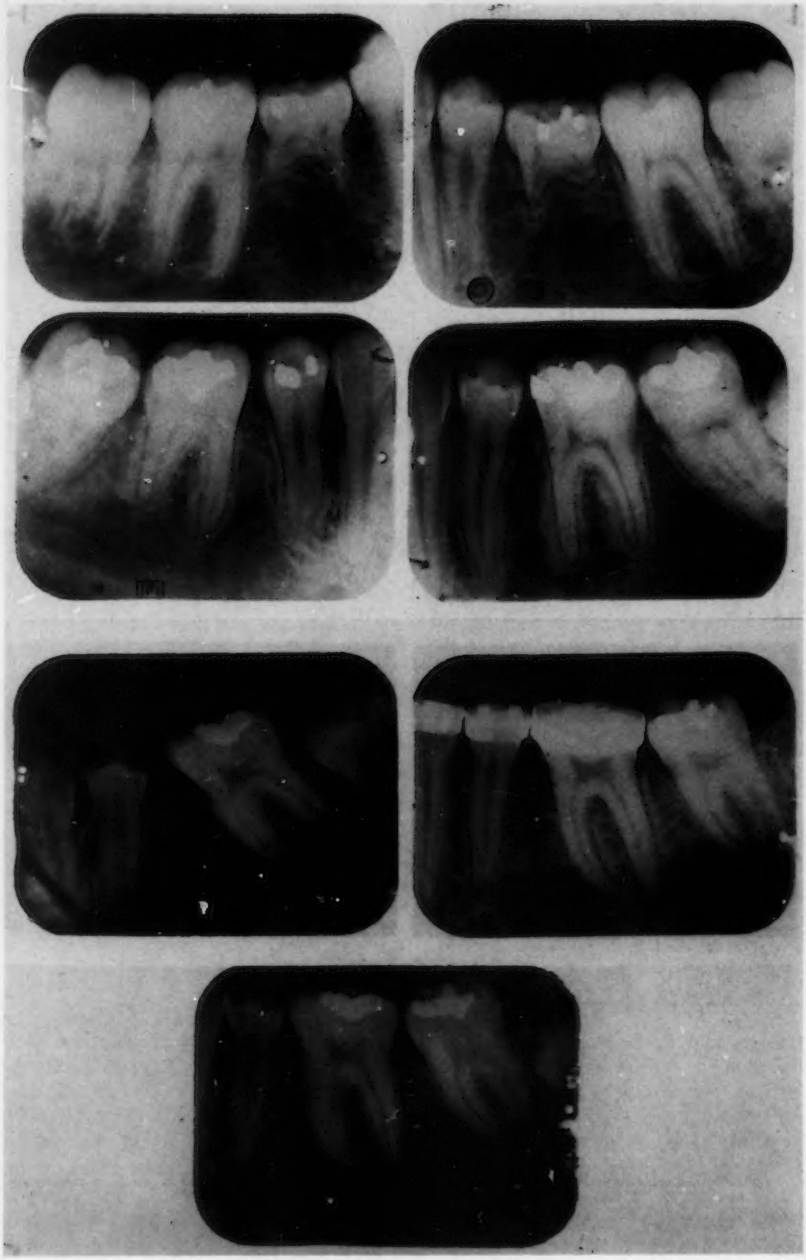

Fig. 5 Above, pre-treatment. Below, post treatment.
Fig. 6 Above left, pre-treatment. Above right, progress x-ray. Below, post-treatment.

Fig. 7 Left, pre-treatment. Right, post-treatment.
Fig. 8 Above, before treatment. Below, after treatment.

molars and upper first premolars were extracted. Lower second premolar spaces were closed by movement of adjacent teeth in both directions. Treatment time: three years.

There is slight resorption of the distal root of the right first molar and moderate resorption of the apical third of the distal root of the left first molar. An upper premolar also showed resorption of one third of the root. Contact between left molar and premolar is open.

Case 4. C. B., female, 9 years. Class I malocclusion, with slight crowding in anterior segments. Lower right second premolar was absent; the deciduous molar was extracted previously. (Fig. 6)

The upper right first premolar was

extracted. Although this unilateral treatment resulted in a slight shift of both maxillary and mandibular midlines to the right, it was felt that the malocclusion did not warrant extractions on the left side. Treatment time: seventeen months.

Final x-ray eight months after removal of appliances shows no root resorption. Occlusion, contacts, and inclinations are good. (Fig. 6)

Case 5. J. M., male, 11 years. Class II, Division 1. Lower left second premolar was absent (Fig. 7); mother and two brothers had congenitally absent teeth.

The deciduous molar was extracted, and intermaxillary elastics used in conjunction with the edgewise appliance. The space was closed approximately one third by distal movement of the canine and premolar, and two thirds by the mesial movement of the molars. Treatment time: twenty-four months.

There has been no root resorption. (Fig. 7). This case is an example of compromise treatment since there was no extraction in the maxilla.

Case 6. T. P., female, 14 years. Class II, Division 1. Lower second premolars, right and left, were congenitally absent. (Fig. 8)

Mechanotherapy as previously described was used. Treatment time: twenty months.

There is resorption of the apical thirds of both right molar roots and, to a lesser extent, of both premolar and left molar roots. (Fig. 8) The maxillary incisors showed severe resorption (more than one third) early in treatment, and the lower incisors, which were not banded for bodily movement, but were *tipped* upright by contact with the arch-wire showed moderate resorption. This patient showed a greater predisposition to resorption than any we have treated.

Root Resorption

It is felt by some that the extensive bodily movements as advocated here predispose to apical root resorption.

Hemley has stated that if teeth were moved by tipping, rather than bodily, there would be no such predisposition. "Accordingly, therapy on 195 consecutive cases was instituted, either with the attempt to avoid movement of apices horizontally through bone, or, in those cases in which it was felt that a horizontal movement was necessary, every effort was made to accomplish this movement as slowly as possible . . . Forty two (21.5%) of the 195 cases treated showed root resorption. . . . . There are all told 172 teeth that showed root resorption, and the total number of teeth subjected to treatment was 4,959: that is, only 3.5% showed any evidence of resorption."[9] Only 62 per cent of the 195 cases were carried to completion, and it is likely that the resorption percentage would be higher had all been completed. Neither were the number of teeth actually subjected to orthodontic forces recorded, nor were the ages of the subjects and the length of treatment compared in the two groups.

Of interest is a more recent statement of Hemley's in a discussion of the Tweed method: "If these abnormal axial inclinations are to be avoided, it would be necessary to move the teeth bodily through bone structure. The attempt to achieve this type of movement, for almost half a century, has been acknowledged to be a failure by Tweed and his followers . . . . . (and) it should be noted that body tooth movement has not been successfully demonstrated since the introduction of root moving devices in 1908."[10]

A *controlled* experiment, in which large numbers of teeth were subjected to both types of movement, would be of value. Until one is performed, this

type of movement cannot be condemned or abandoned.

Phillips, in a recent investigation which merits attention, attempted a correlation between the degree of resorption and the type of movement of the maxillary central incisors in sixty-nine cases completed with the edgewise appliance. "No correlation between the distance a tooth is moved during treatment could be shown with the amount of apical root resorption during treatment . . . . . No significant difference could be drawn between the amount of apical root loss resulting from the three various types of movement (apical tipping, anterior or posterior apical displacement, lingual bodily movement.)"[11]

Halderson et al. compared the tissue reactions of different appliances. "The extremes of force used in the *edgewise mechanism* make it imperative that sufficient time elapse between appointments to allow the periodontal membrane to recover from the insult and injury of the appliance. Histologic studies on human beings indicate that, for this appliance, as it is ordinarily used, three weeks is a minimum period between adjustments (Gottlieb) . . . . . The edgewise mechanism operates, more than any other appliance, in the realm of controlled pathology. It would be of little practical clinical use if this were not true; yet this fact is often neglected. The clinician who adjusts the appliance with forces of such severity that he routinely prescribes aspirin after weekly appointments is not only endangering the tissues with which he works, but he is also failing to use an excellent mechanism to best advantage and is making a great deal of extra work for himself."[12]

Discussing the *twin wire appliance* in the same article, they state that "the greatest danger in this appliance lies in the distance through which the force may be applied to a tooth. There is a temptation to keep the force, light though it be, active for too long a time and too great a distance. During animal experimentation it was found to be *easier to cause root resorption with this than any other appliance tested.* (italics ours). In spite of the light weight, the pressure may be far too continuous for safety."

This is in accord with the original investigations of Oppenheim[13] who warned that physiologic orthodontic movement is not possible but, to decrease the amount of permanent injury the moving force should be light and intermittent, with frequent periods of rest.

If we accept these principles, it will be seen that a Bull loop incorporated into an edgewise arch is as "physiologic" as an appliance can be. The force resulting from the prescribed one millimeter opening expends itself in about two days, mostly in the region of the peridental space which has been widened by the previous application of lighter arch wires. The vertical legs are then in contact with each other, affording a degree of stability or splinting to the recently traumatized dental and peridental tissues, and allowing the reparative processes to take place in the three week or greater interval.

There are other theories to explain apical resorption during treatment, all of which undoubtedly hold true in certain cases.

Becks, in numerous reports on this subject, stresses the association between susceptibility to resorption and endocrine disorders (hypo-thyroidism, and less frequently, hyperpituitarism) and acute and chronic infectious diseases which disturb general mineral metabolism. "I am decidedly of the opinion that the root resorptions observed in orthodontic practice are produced not by mechanical force *alone,* but that

they are rather the result of an individual predisposition to increased resorptive activity."[14] He found the percentage of cases of root resorption twice as high in patients with osteoporotic jaws as in those with normal structure.

Rudolph[15] reports that the percentage of resorption progresses with each year of treatment and with increased age at onset of treatment. Fischer agrees that "the age of the patient and the length of orthodontic treatment bear a direct relationship to the incidence and extent of root resorption."[16]

As every orthodontist knows, root resorption in certain cases is inevitable and its effect on the health and longevity of the dentition merits our attention. With the termination of treatment the process ceases and teeth exhibiting apical resorption show no greater than average mobility.

Jacobson, in a paper entitled the *"Clinical Significance of Root Resorption"* solicited opinions on this subject; Dr. Samuel Charles Miller, a clinician (periodontist) of wide experience, states that root end resorption is of 'no great significance except in differential diagnosis'. . . . . Dr. Allan Brodie pointed out, 'The importance of the process from a clinical standpoint has been greatly overestimated. The retention apparatus of the tooth is largely restricted to the coronal 2-3rds of the root - its apical ⅓ is relatively functionless in this regard. The loss of even a small degree of alveolar height (at the crest) is of greater significance'."[17] Jacobson emphasizes that, among other factors, it is not the kind of appliance that has any connection with the character of resorption, but "what the appliance is made to do."

We are in agreement that skill, patience, and judgment in the use of the edgewise appliance, as advocated here for extensive space closure, will cause no greater than the usual incidence of apical resorptions, found to occur in certain cases regardless of the type of movement or the type of appliance used.

Summary and Conclusions

1. Congenitally absent premolars are seen frequently in orthodontic practice.
2. Space closure avoids the disadvantages of prosthetic replacement.
3. An orthodontic approach to the problem is offered, explained and illustrated with case reports.
4. The problem is a complex one and, of necessity, the solution is also. It is presented as a worth-while service in many cases and not as a panacea.
5. The relation of this type of tooth movement to apical resorption is discussed; the latter need not be a deterrent to the method proposed.

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Aspects of Growth in the Cranium, Mandible, and Teeth of the Rabbit as Revealed Through the Use of Alizarin and Metallic Implants

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Our knowledge of osseous growth in the cranium has come from many sources. Important studies have been carried out in man, using cephalometric roentgenograms, and in living animals through the use of cephalometric procedures, metallic implants and vital dyes. Broadbent, in 1930, commenced a long-range growth study on humans in the course of which he developed a reliable instrument for the taking of cephalometric head films.[6] Through the use of this instrument, the Broadbent-Bolton cephalometer, Broadbent has been able to record craniometric points accurately and repeatedly over many years.

Cephalometric studies have since been carried out on a variety of animals. To facilitate this type of work, Jarabak designed an animal-head fixation attachment which could be placed on the Broadbent-Bolton cephalometer.[12] Recently (1953) Selman and Sarnat succeeded in further adapting the cephalometer to the anatomy of the rabbit head by a change in the head post angulation of the apparatus.[27] An attachment similar to that of Jarabak's was adapted for the taking of head plates during the present study.

Metallic implants have been used on numerous occasions in the study of animal growth. Selman and Sarnat employed cranial and facial implants in rabbits, while Gans and Sarnat used them in the Macaca Rhesus monkey.[25 26 11] Robinson and Sarnat, on the other hand, confined their implant study to the pig mandible.[24] Levine, working with rabbits, employed cranial metal implants, but also used alizarin concurrently to demarcate growth.[16]

More recently an introduction to the use of metallic implants in the study of facial growth in man has been made by Bjork. Cephalometrics and metallic implants were used concurrently and preliminary data on the vertical development of the face and the mode of eruption of the teeth were obtained.[4]

The vital dye, alizarin red S, has been used many times to demonstrate growth in animals.[21 22 29 31] In an early and extensive work, Brash fed alizarin to pigs in its natural form (within madder) and studied the bone growth lines which were formed in due course.[5] Most investigators, however, have used the synthetic form of the dye (alizarin red S) because of its broader range of usefulness.[2 8 9 13 15]

When administered in vivo, alizarin red S becomes linked to metallic hydroxides present at calcification sites

*Thesis presented in partial fulfillment of the requirements for the Degree of Doctor of Dental Surgery. University of Washington, Seattle, June 1954.

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within the body and insoluble dye "lakes" are formed. So rapid is this union of dye with hydroxide that, within fifteen minutes of an alizarin injection, a permanent marking line is formed in all dentin and bone calcifying at that time. This tinctorial activity of alizarin red S has been studied by Hoffman through the use of an artificial bone matrix. It is evident that the dye has a selective staining effect upon the calcifying or calcio-receptive zone of the collagenous matrix within which the calcium salts are being deposited.[30]

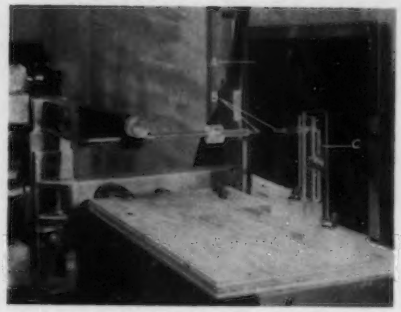


Fig. 1 Broadbent Bolton cephalometer head holder attachment for rabbits. A. film cassette; B. earposts; C. anterior post for centering and holding the upper incisors.

Methods and Materials

The young New Zealand rabbit was selected as an animal well suited to a study of dental and osseous growth. Preparatory to actual experimentation with the animal, it was found necessary to devise a technique for the taking of serial roentgenograms of the rabbit on the cephalometer. A special cephalometric attachment was designed, consisting of a plywood base with plastic up-rights upon which were mounted: 1) an ear post and 2) an anterior post for centering and holding the upper anterior teeth of the rabbit. Another plastic ear insert was machined to fit one of the ear posts on the cephalometer. In this way, the entire attachment was oriented exactly in the midsagittal plane and the transmeatal axis of the cephalometer (Fig. 1). Thus, a fixed target distance and fixed film placement were obtained. Exposure time was subsequently evolved through trials with a rabbit head on this apparatus.

Before detailed experimentation on the rabbit could be undertaken, it was necessary to determine the commensurate dosage which would give recognizable markings in the cranial bone of the rabbit, and which would at the same time be within the tolerance range of the animal. For these reasons, introductory experiments were conducted upon two eight-week old New Zealand rabbits. One rabbit served as the control, the other as the experimental. Two injections of alizarin red S were given this latter animal within the dosage range 50-100 mg./kg. of body weight as established by Schour et al.[30] The first injection was made at the level of 50 mg./kg. of body weight and the second at the level of 75 mg./kg. of body weight. When the animal was sacrificed, it proved extremely difficult to locate the first alizarin red S line. The line resulting from the second injection was visible upon the bone surface, but did not demonstrate the areas of growth as strongly as might have been desired. No toxic effect was noted following the injection of either quantity of alizarin red S. For this reason, the maximum dosage (100 mg./kg. body weight), presumably well within the tolerance range, was considered preferable in terms of the bone marking which it would produce.

The experiment proper was built around a group of six New Zealand rabbits, 8 weeks of age. Five rabbits served as experimentals, the sixth as a control. At the outset, metal implants were placed surgically on each side of the fronto-parietal and fronto-nasal

sutures of the cranium in all experimental animals. Each rabbit was then given an intraperitoneal injection of a 2% solution of alizarin red S in 0.45% sodium chloride (100 mg./kg. of body weight).

A second injection was given 32 days later. The animals were sacrificed 14 days after this second injection. Just seven days before the animals were sacrificed, a mark was placed on the upper and lower anterior teeth at the free gingival margin. Two animals died prior to the termination of the experiment; one at the time of surgery, because of an overdose of nembutal, and the other after the second injection of alizarin for unknown reasons.

The rabbits were fed twice daily a ration of cereal grains and mash concentrates. Greens were given twice weekly. They were weighed every day for the first four days and then every other day.

Roentgenograms were taken under nembutal narcosis at the time when the metal implants were placed, at the time of the second injection, and at the time of sacrifice. At the time of sacrifice, records were also made of the distances, (a) between the amalgam inserts on the cranial surface, and (b) between the horizontal marks upon the anterior teeth and the free gingival margin. The heads were then placed in a 10% formalin solution and, several days following this, the soft tissue was removed from about the skulls.

Experimental Results

A. Roentgenographs

Tracings of the three successive films showed that the inserts moved apart an average of 3.86 mm. at the fronto-nasal sutures and an average of 0.766 mm. at the fronto-parietal sutures during the entire period studied. There was, in other words, five times more growth at the fronto-nasal sutures than at the fronto-parietal sutures. The two

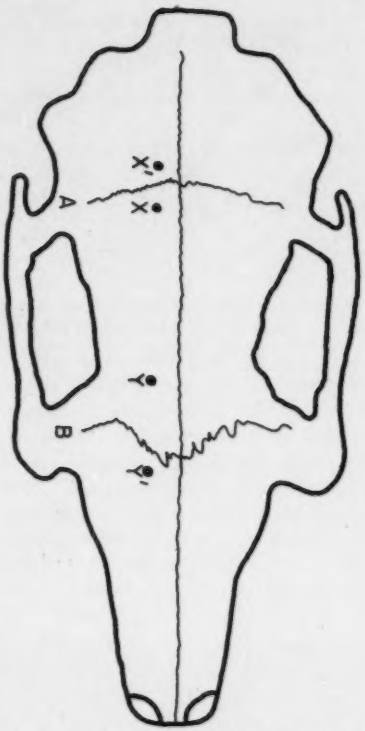


Fig. 2 Tracing of superior view of skull showing location of metal inserts. A. fronto-parietal suture; B. fronto-nasal suture; X', X, Y, Y', metal inserts.

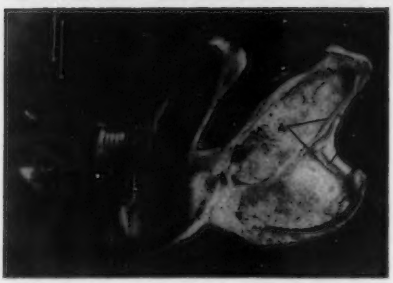
inserts (X and Y) in the frontal bone proper showed no movement apart (Fig. 2), demonstrating further that longitudinal growth of this bone is concentrated in the area of the suture line. Using these two inserts as a guide in superimposing the roentgenogram tracings, a definite growth pattern of the head in a forward and downward direction could be observed (Fig. 3). Furthermore, under dissecting microscope inspection, there could be observed overlying each metal insert a film of dense tissue resembling new osteoid bone.

B. Alizarin red S

Since a decalcification procedure

Fig. 3 Roentgenographic tracings superimposed on X and Y to show forward and downward growth pattern. X', metal insert in parietal bone. Y' metal insert in nasal bone. X and Y metal inserts within the frontal bone.

would have removed alizarin red S, it was necessary to base the experimental analysis upon visual observation of gross specimens and microscopic observation of ground sections of the bones and teeth.



Figs. 4 & 5 Lateral and lingual views of mandible. A. line produced by first injection of alizarin red S; B. line produced by second injection of alizarin red S.

The surfaces of the skull and mandible were completely covered by the alizarin red S, showing that appositional growth was generalized. The posterior border of the mandible and the condylar region showed two definite alizarin lines from the two injections (Figs. 4 and 5). Similar lines were visible in the alveolar process surrounding the mandibular central incisor (Fig. 6). The alveolar processes generally showed heavy staining.

The teeth in animals subjected to

Figs. 6 & 7 Superior views of lower incisors. E - experimental animals; C - control animal. a. line produced in dentin by first injection of alizarin red S; b. line produced in dentin by second injection of alizarin red S; A. line produced in alveolar process by first injection of alizarin red S; B. line produced in alveolar process by second injection of alizarin red S.

Lateral view of skull and mandible with alveolar bone removed. A. apical termination of line produced by first injection of alizarin red S; B. apical termination of line produced by second injection of alizarin red S.

alizarin red S also showed distinct red lines in the many ground sections prepared. In ground cross sections there were dual lines one within the other. Distance measured between these lines, divided by the number of days between injections, gave the daily appositional growth rate of the dentin. On their external facial surfaces the teeth were marked by two red bands which actually formed the apical terminations of two internal cones (Fig. 7). A measurement made between the apical terminations of these two successive bands or cones on the external surfaces, divided by the number of days between injections, gave the daily eruption rate of the teeth. For the upper and lower incisors, measurements of both labial and lingual surfaces were obtained and the mean eruption rate was determined. The total measured length of the teeth divided by this calculated eruption rate provided the estimate of the time required for complete replacement of these teeth.

As a further check on the eruption rate of the anterior teeth, measurements were made between the prepared mark cut in the enamel and the free gingival margin. This latter procedure lacked complete accuracy in that the free gingival margin was quite movable. The average distance measured between tooth mark and free gingival margin was 2.2 mm. for the upper incisors, and 2.3 mm. for the lower incisors. A range of plus or minus 0.3 mm. was noted.

When the distance between alizarin lines on the facial surfaces of the teeth was measured, the average weekly eruption rate calculated for the upper incisors was 2.0 mm. and for the lower incisors, 2.36 mm. As noted in Table I, the lower teeth were erupting a little faster than the upper. The calculated replacement time for the upper incisors was 12 weeks, for the lower incisors, 10 weeks and for the upper and lower posterior teeth, 10 weeks. The third molars showed extreme variation in their growth rates from one animal to another. In one animal, for instance, the estimated third molar replacement time was 7 weeks, while in another, it was 32 weeks.

Cross sections were made of certain teeth in the upper and lower dental arch of each animal. Teeth of the upper arch which were studied included the central incisors, the first, second and third premolars, and the first and second molars. The lower teeth studied

TABLE I

WEEKLY ERUPTION RATE OF TEETH

Teeth	*Number of Measurements*	*Mean* *	*Standard Error of Mean*	*Standard Deviation*
Upper Central Incisors	6	2.00 ± .18 mm		.44
Lower Central Incisors	6	2.36 ± .11 mm		.289
Upper Posterior Teeth	18	1.19 ± .09 mm		.40
Lower Posterior Teeth	15	1.30 ± .07 mm		.30
All Teeth	45	1.71 ± .05 mm		.34

*Millimeters per week.

TABLE II

APPOSITION OF DENTIN PER DAY

Teeth	*Number of Measurements*	* *Mean*	*Standard Error of Mean*	*Standard Deviation*
Upper Central Incisors	24	12.00	± .58	2.88
Lower Central Incisors	24	12.76	± .53	2.61
Upper Posterior Teeth	103	10.99	± .40	4.14
Lower Posterior Teeth	105	10.10	± .49	5.05
All Teeth	256	11.46	± .26	4.31

*Microns per day.

were the central incisors, the first and second premolars, and first and second molars. Ground sections were made of each tooth (Figs. 8 and 9). In each section the distance between the lines produced by the alizarin was recorded. Eight or more measurements were made on each section. The measured distance divided by the number of days between the injections gave the daily appositional growth rate of the dentin (Table II).

The average daily apposition of dentin was calculated to be 11.46 microns. The observed rate of apposition varied considerably from a minimum of 1.87 microns a day to a maximum of 20.93 microns per day.

C. Weight variations

The experimental animals demonstrated a weight loss following each injection of alizarin red S. This weight loss continued on each occasion for three to four days.

The control animal was kept in the same environment and given care identical to that received by the experimental animals. By contrast, no surgery was performed upon this control animal and no injections were administered to it. The first weight loss registered by the control, almost paralleling in time and severity the weight loss of the experimentals at the time of first injection, may be attributed

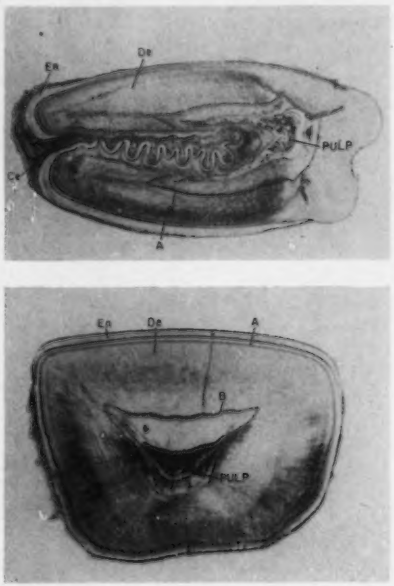


Fig. 8 & 9 Cross section of lower incisor. A. line produced in dentin by first injection of alizarin red S; B. line produced in dentin by second injection of alizarin red S; En - enamel; De - dentin.

Cross section of upper first molar. A. line produced in dentin by first injection of alizarin red S; B. line produced by second injection of alizarin red S; En - enamel; De - dentin; Ce - cementum.

to an accidental water deprivation for five to eight hours. The weight drop seen in the control on the 42nd day was in all likelihood produced by a similar, short-term, accidental dehydration.

Discussion

A. Appositional growth and calcification

Appositional growth and calcification are two different processes, characteristic of bone, enamel, cementum and dentin. Even though these processes are separate and distinct, with calcification following the appositional growth, the two are closely associated with one another. In this connection Schour and Hoffman point out that "the rate of incremental calcification and the rate of apposition in enamel and dentin are the same, and the calcification pattern under normal conditions acts as a reliable indicator of the growth pattern."[29] When the alizarin red S injection is employed, it is the incremental pattern of calcification that is being measured, rather than the appositional growth.

Such a sequence is well illustrated in dentin. As one layer of organic matrix material or predentin is being produced under odontoblast cell influence, the predentin formed the previous day is undergoing calcification.[28] Thus, when the predentin reaches a width in the range of 10-20 microns, that portion of it farthest from the odontoblasts becomes a newly calcified zone known as the intermediate dentin.[28] This is the zone that is stained by the alizarin red S in the initial stages of calcification.

B. Dentition of the rabbit

The teeth of the rabbit grow and erupt continuously throughout the life of the animal. These continuously erupting teeth are referred to as teeth of persistent growth.[28] No structural distinction is made between crown and root in this situation. Instead, a single crown exists, the constant growth of which is due to the continuous apposition of tissue at the basal portion.

Because of varied growth rates on the labial, buccal, and lingual surfaces, brought about by differential cellular activity of the epithelial base, all the teeth exhibit a distinct curvature (Fig. 7). This is seen most readily in the upper and lower incisors, although the upper premolars and molars do have a slight buccal curvature and the lower premolars and molars a slight mesiodistal one.

C. Eruption

Because of the pronounced curvature of the upper and lower incisors, a single mark placed only on the labial surface of the tooth does not give the average eruption rate for the entire tooth. Preferably a mark should be placed on both the labial and lingual surfaces. An even more accurate determination can be made by using the basal termination of each alizarin band. Such a procedure was followed here. Measurements were made on each side of the tooth and the mean eruption rate was determined from these figures.

D. Growth of dentin

The daily appositional rate of dentin varies within a single tooth and between different teeth. This variation is dependent upon the anatomy of the tooth, the amount of tooth structure already formed, the position of the tooth, the method of sectioning and measuring, and the age and species of the animal. In the rabbit upper incisors, for example, growth of dentin was found to vary from 4.68 microns in one area to 15.62 microns in another, while in lower incisors the range was 7.81 to 18.43 microns. Schour and Hoffman point out that, even though there is a marked growth gradient within a single tooth, it follows a definite and orderly pattern of distribution.[29]

The posterior teeth demonstrated the most variation in growth. Their com-

plex geometrical configuration greatly influenced the measurements taken and it was with difficulty that an accurate mean of their growth was obtained.

E. Cranial growth

Both this study and that of Levine reveal that there is approximately five times as much growth at the fronto-nasal suture as at the fronto-parietal suture, and that this growth differential produces an elongation of the face in an anterior direction.[16] Levine attributes the relative lack of activity at the fronto-parietal suture to an early stabilization of the cranium. Selman and Sarnat, while investigating growth at the fronto-nasal suture of the rabbit, measured the distance between metal implant and suture line as well as the distance between metal implants. They found that approximately 65% of the total growth at the suture could be attributed to the nasal bone and approximately 35% to the frontal bone.[25]

The mechanisms of cranial growth are still being investigated and debated. Majority opinion credits the primary growth of the cranium to sutural activity. Brash, on the contrary, did not attribute the primary increase in size of the cranium to suture line activity, but rather explained such growth on the basis of surface accretion and surface absorption.[5] Where growth sites in maxilla and mandible are concerned, however, the findings of Brash are not at variance. Likewise, Robinson and Sarnat, through the use of metal implants in the pig mandible, demonstrated the same growth sites that have been brought out here by the use of alizarin red S.[24] In the present study, growth at the suture lines was demonstrated both by metal implants and by alizarin red S injection. Moore and Craven, using the latter technique, and Jarabak, et al., using radioactive calcium, have also demonstrated growth at the suture lines and have suggested this mechanism to be fundamental to cranial enlargement.[22 9 14]

Conclusions

1. The major portion of cranial growth took place at the suture lines.
2. Measurements made of the distance between metal inserts at two cranial suture lines showed an average separation of 0.766 mm. at the fronto-parietal suture and 3.86 mm. at the fronto-nasal suture. These observations demonstrated that there was five times as much growth at the fronto-nasal suture as at the fronto-parietal. Such growth differentiation between the cranial and facial portions may be characteristic of long snouted animals.
3. The cranium showed marked appositional growth on all internal and external surfaces.
4. In the mandible the location of alizarin lines showed the growth sites to be at the posterior border of the ascending ramus, in the condylar region and in the alveolar process.
5. In the incisal region of the mandible, the growth appeared localized to the superior one-third of the alveolar process.
6. Both maxilla and mandible showed marked appositional growth over the entire alveolar process in the molar area.
7. The average daily increment of dentin in the upper incisors was found to be 12.00 microns; in the lower incisors, 12.76 microns; in the upper posterior teeth, 10.99 microns; in the lower posterior teeth, 10.10 microns. An overall average rate of dentin formation of 11.46 microns per day was noted.
8. The eruption rate for the upper incisors was calculated to be 2.00 mm. per week; for the lower incisors, 2.36 mm. per week; for the

upper posteriors, 1.19 mm. per week; and for the lower posteriors, 1.30 mm. per week. The overall average rate of tooth eruption was 1.71 mm. per week.

9. The use of metal implants and the vital dye alizarin red S has been shown to be of great value in the study of normal growth.

Summary

A study was conducted on New Zealand rabbits to determine the rate of growth at the fronto-parietal and fronto-nasal sutures, to follow the pattern of cranial growth, to determine the appositional rate of growth in the dentin and to ascertain the eruption rate of the anterior teeth. The use of metallic implants and the employment of serial roentgenograms made it possible to trace the rate of growth at the suture lines as well as the general pattern of cranial growth. Appositional growth rate in the dentin and the eruption rate of the teeth were determined by means of peritoneal injections of alizarin red S.

Two groups of rabbits were studied. The first group was used to determine the dosage levels of alizarin necessary to reveal growth in bones and dentition. On the basis of results with these first animals, it was found that dosages of 50 and 75 mg. alizarin per kilogram body weight, although well tolerated, did not demonstrate the areas of growth as strongly as might have been desired.

The second group consisted of five experimentals and one control animal. The experimentals were given two injections of 100 milligrams of alizarin red S per kilogram of body weight 32 days apart. This alizarin dosage revealed satisfactorily the growth sites in the skull and mandible and the incremental growth pattern in the teeth.

Cranial expansion was found to occur primarily as a result of bone growth at the suture lines, although pronounced appositional growth was evident on the internal and external surfaces of all cranial bones. Appositional bone growth was also very noticeable upon the posterior border of the ramus and upon the alveolar process of both maxilla and mandible in the molar area.

The growth differentiation between the cranial and facial portions of the head may be characteristic of long-snouted animals. Five times as much growth occurred in a given time interval at the fronto-nasal suture as at the fronto-parietal suture.

Apposition of dentin in the teeth of the rabbit occurs at the mean rate of 11.46 microns per day while eruption of the teeth preceedes at the mean rate of 1·71 mm. per week.

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Anna Hopkins Angle

Anna Hopkins was born on a farm in Bloomington, Minnesota, January 22, 1872. She was the first of eight children. Farm life, difficult anywhere at that time, was especially hard in that northern country with its long, cold winters and its short growing season. As fast as a child grew enough to do even the simplest things, it was given tasks which became its sole responsibility. Needless to say, the oldest child carried the heaviest load and, as each new one arrived, there were new tasks, new responsibilities.

Anna grew up early. She took her ordinary chores as a part of living and was constantly looking for more things to do. Throughout her life she gloried in the simple tasks of the home and whatever she did was done with the skill that comes from long practice.

When she was old enough, Anna was sent to school No. 10, a typical country school of the times. There she went through all the grades and finished her education at fourteen. We can imagine that going to school was a joy for her because at all other times she was fully occupied with farm chores and helping the younger children.

As soon as she had finished her own schooling, she began to teach at the same school and, with the meager salary she derived from this, began to supply her own needs. By the age of sixteen she was not only self-supporting but helping the family as well. The material things of life were always scarce on the Hopkins' farm, but books were always considered a necessity.

Sensing the limitations of her environment, Anna left the farm when she was sixteen and went to Minneapolis to take courses in bookkeeping and secretarial work. But this was no "running away from home." Her strong sense of responsibility to her family never diminished throughout her life. She continued always to help them and as late as 1931, following Dr. Angle's death, she assumed complete responsibility for the two orphan daughters of one of her brothers and took them to California to live with her. She never visited the middle west without going to the farm.

After completing her training, Anna obtained a position with a large business concern in Minneapolis and continued to go to school at night. It must have been about 1893 that she took a position as secretary to Dr. Angle. It was in that year that he published the third edition of "The Angle System of Regulation and Retention of the Teeth" and the fourth edition appeared in 1895. Knowing the agony he went through in writing anything for publication, it is quite likely that his need for a secretary was very great during those years. It is also understandable that Anna could not be in contact with Dr. Angle for very long before she fell under the same spell that held him to orthodontia. At any rate, she felt the need for further training and, accordingly, entered the University of Iowa to study dentistry.

Following her professional training she once more joined Dr. Angle, who had moved to St. Louis in the meantime. It was here he gave his first course of instruction in 1900 and, in 1901, organized the American Society of Orthodontia. The records show that Anna Hopkins was secretary of the society from 1902 to 1905. Some time during the interval between 1900 and 1902,

she took her own orthodontic training. She married Dr. Angle in 1906 in Niagara Falls, New York.

The orthodontic literature of that period gives us a fairly accurate idea of what conditions were like. We know that orthodontia was witnessing the aligning of different groups, each headed by a strong personality, and that the strife that raged among them was far more violent than anything we know today.

Angle, although a sensitive man, was a hard fighter and he brought down upon his own head storm after storm of criticism and abuse. Such times were difficult for Anna. With her strong protective instincts she could only encourage and give him comfort when he was hurt, because it is doubtful that she ever was able to cause him to alter his course; even more doubtful that she would try to, knowing his strong convictions.

Her patience was endless. Dr. Angle came more and more to depend upon her, particularly in the writing of his papers. She would take down dictation as he sat and thought aloud and then, when she read it back to him, he would swear he had not said it that way. Then the whole thing would have to be done over and over again, each paragraph, each sentence, each word, until it expressed just what he wished, no more, no less. Mrs. Angle laughingly said later that she came closer to divorce when writing papers than at any other time.

In spite of her complete devotion to Dr. Angle and his work, Mrs. Angle had a whole world of interests of her own. She was an avid reader over a large range of subjects and could converse intelligently on all of them, but she had the rare trait of concealing more than she revealed of her knowledge and she never forced her opinion. Like most people of this sort, she attracted friends wherever she went and to these, as well as the various causes that she espoused, she gave more than casual interest.

When the Angle course was started again in Pasadena, a considerable interval of time had elapsed since the New London days and the students were more widely separated from the Angles in age. To these younger men, Mrs. Angle was invariably "Mother" and many of them could thank her influence for smoothing their way when they were verbally "spanked" by Dr. Angle. However, she was always careful not to carry her sympathy so far that the intended lesson did no good, for she, too, believed in discipline.

The wives, too, felt her influence and there is no doubt that they took away from Pasadena more than recipes for delicious dishes. For them she was a model to be emulated.

The school closed its doors to students in 1927 and Dr. Angle died in 1930. During the last years of his life the Angle Society continued to hold its meetings in the little building. When the present society was organized in 1930 following Dr. Angle's death, Mrs. Angle journeyed to Chicago to assist the founders. She was made Honorary Chairman of the Executive Committee for life and an editor of the Angle Orthodontist. She never exercised the prerogatives of either office, although she attended the biennial meetings until 1949 wherever they were held. The Southern California Component continued to hold its meetings at the little school, now her home, until recently.

Thrust into a role of prominence as the wife of a world figure, Anna Hopkins played her role with grace, modesty, and an exquisite sense of the fitness of things. Had she been destined to a life of obscurity, she would still have made the lives of those around

her richer by those beautiful womanly characteristics that made her so dear to us.

With her passing this society has lost its closest link with Dr. Angle. But though the life may be gone, the ideals and inspiration which she gave us will live forever in the hearts of the present members of the society who were privileged to know her.

A. G. B.

The Angle Orthodontist

A magazine established by the co-workers of Edward H. Angle, in his memory . . .

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Vol. XXVIII, No. 1 January, 1958

The Angle Orthodontist

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Do not use symbols to indicate teeth; in *tables* teeth may be designated as U-1 or L-6, but in the text names of teeth should be fully written out.

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